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Bethesda, Maryland 20034

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VULNERABILITY OF THE JEFF(A) AND JEFF(B) AMPHIBIOUS ASSAULT LANDING CRAFT (AALC) TO IMPACT DURING DOCKING WITH AN LPD/LSD

by

William E. Gilbert

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STRUCTURES DEPARTMENT
RESEARCH AND DEVELOPMENT REPORT

June 1975 Report 4664

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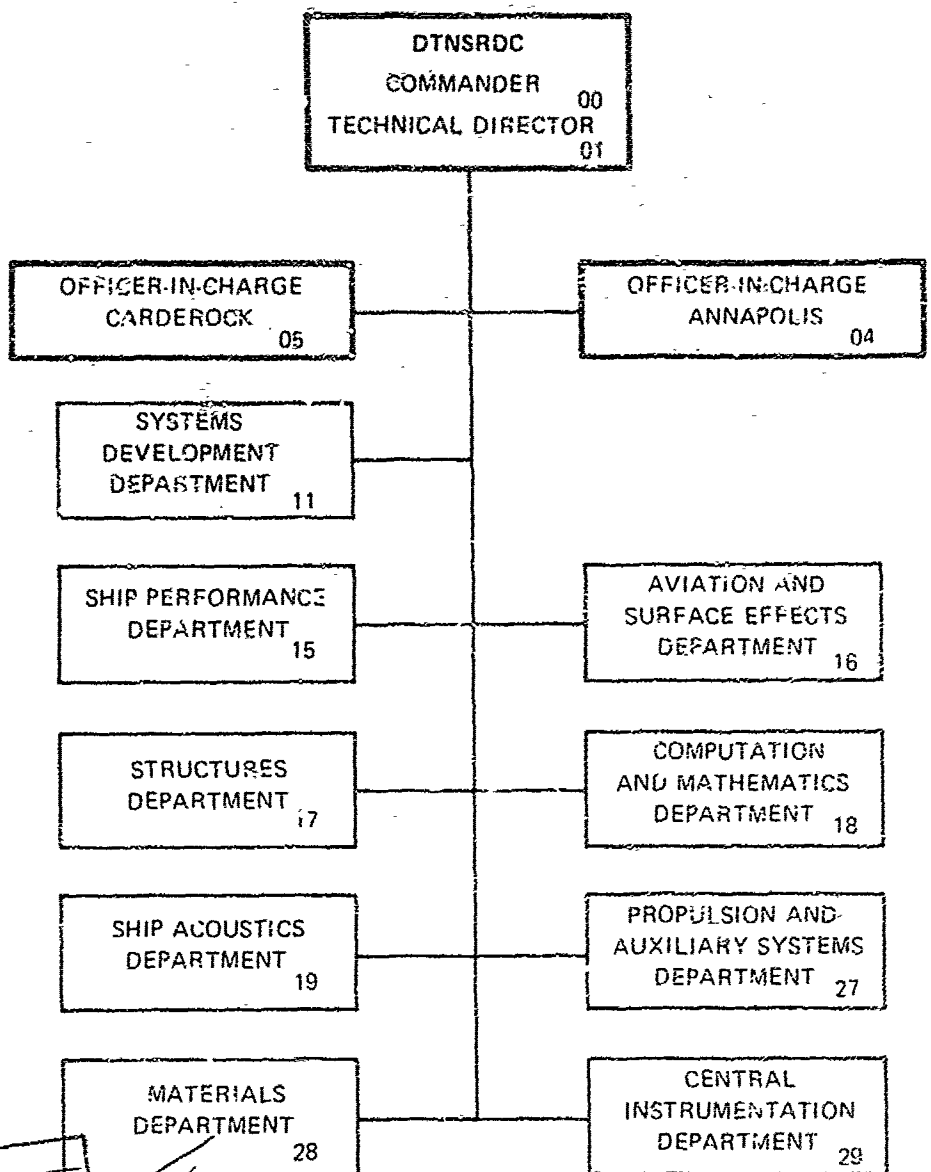

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Two prototype air cushion vehicle (ACV) amphibious assault landing craft (AALC) designated the JEFF(A) and JEFF(B) are being respectively developed by Aerojet General Corporation, Tacoma, Washington, and Bell Aerospace Company, New Orleans, Louisiana. Each craft weighs approximately 170 tons, fully loaded, and is supported on a cushion of

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to 1473B

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(Block 20 continued)

from 1473A

air contained by a flexible skirt system which circumscribes the lower outer perimeter of the craft. The JEFF/AALC craft are able to operate at high speeds over both water and land and will serve to deliver personnel, equipment, and supplies from an offshore amphibious assault ship to a shore landing area.

Docking impact can occur when a JEFF craft enters the well deck of an amphibious assault ship such as the LPD (amphibious transport, dock) or LSD (landing ship, dock). The impacts that can occur during docking are potentially dangerous because of the lightweight construction of the JEFF. Accordingly, the rigid body motions of the craft were investigated for an assumed set of docking cases, and energy-absorbing capabilities and characteristics were calculated for the pressurized skirt system, the protective bumpers, and the hard structure of both configurations of the experimental prototype craft. The present report analyzes vulnerability to docking collision, recommends modifications to the proposed bumper protection system, and makes suggestions concerning operational methods of docking to reduce collision hazards.

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ABSTRACT

Two prototype air cushion vehicle (ACV) amphibious assault landing craft (AALC) designated the JEFF(A) and JEFF(B) are being respectively developed by Aeroject General Corporation, Tacoma, Washington, and Bell Aerospace Company, New Orleans, Louisiana. Each craft weighs approximately 170 tons, fully loaded, and is supported on a cushion of air contained by a flexible skirt system which circumscribes the lower outer perimeter of the craft. The JEFF/AALC craft are able to operate at high speeds over both water and land and will serve to deliver personnel, equipment, and supplies from an offshore amphibious assault ship to a shore landing area.

Docking impact can occur when a JEFF craft enters the well deck of an amphibious assault ship such as the LPD (amphibious transport, dock) or LSD (landing ship, dock). The impacts that can occur during docking are potentially dangerous because of the lightweight construction of the JEFF. Accordingly, the rigid body motions of the craft were investigated for an assumed set of docking cases, and energy-absorbing capabilities and characteristics were calculated for the pressurized skirt system, the protective bumpers, and the hard structure of both configurations of the experimental prototype craft. The present report analyzes vulnerability to docking collision, recommends modifications to the proposed bumper protection system, and makes suggestions concerning operational methods of docking to reduce collision hazards.

ADMINISTRATIVE INFORMATION

The study was sponsored by the Advanced Technology Systems Division of the Naval Sea Systems Command (NAVSEA Code 032) and administered by the Amphibious Assault Landing Craft Program Office (Code 118) at t! Naval Ship Research and Development Center (NSRDC). Funding was provided unde. Program Element 63566N, Project S1417, Task Area S1417 (Amphibious Assault Landing Craft Program Shipboard and Beach Handling), Work Unit 1-1180-007.

INTRODUCTION

The objective of the Amphibious Assault Landing Craft (AALC) Program[1] is to define, develop, demonstrate, and document an advanced landing craft system which will substantially

[1] "Test Trials and Training Master Plan or Advanced Development Objective 14-17 X of February 1968," Amphibious Assault Landing Craft Program, Project S14-17 (31 Mar 1974). A complete listing of references is given on page 129.

improve both operational flexibility and the cost effectiveness of ship-to-shore movement of personnel and material. Particular emphasis is placed on providing the Fleet with the capability to launch amphibious assault operations from over-the-horizon. The developmental prototype JEFF craft, Figure 1, will be used to fully assess the feasibility of applying air cushion vehicle (ACV) technology to high-performance landing craft configurations capable of meeting the requirements of the 1980 time frame and beyond.

The JEFF craft being developed under this advanced development program are full-scale (approximately 90 ft long, 48-ft beam) developmental protoype, 170-ton amphibious vehicles. Their designation as ACV's indicates that these craft are supported on a cushion of pressurized air, contained by a flexible skirt system. The low drag of the ACV enables the attainment of higher speeds than possible for a conventional displacement craft.

The structural design of the JEFF is necessarily lightweight; it resembles aircraft structural practice more than conventional ship design in order to minimize lift system power requirements. Table 1 presents the principal characteristics of the JEFF craft.

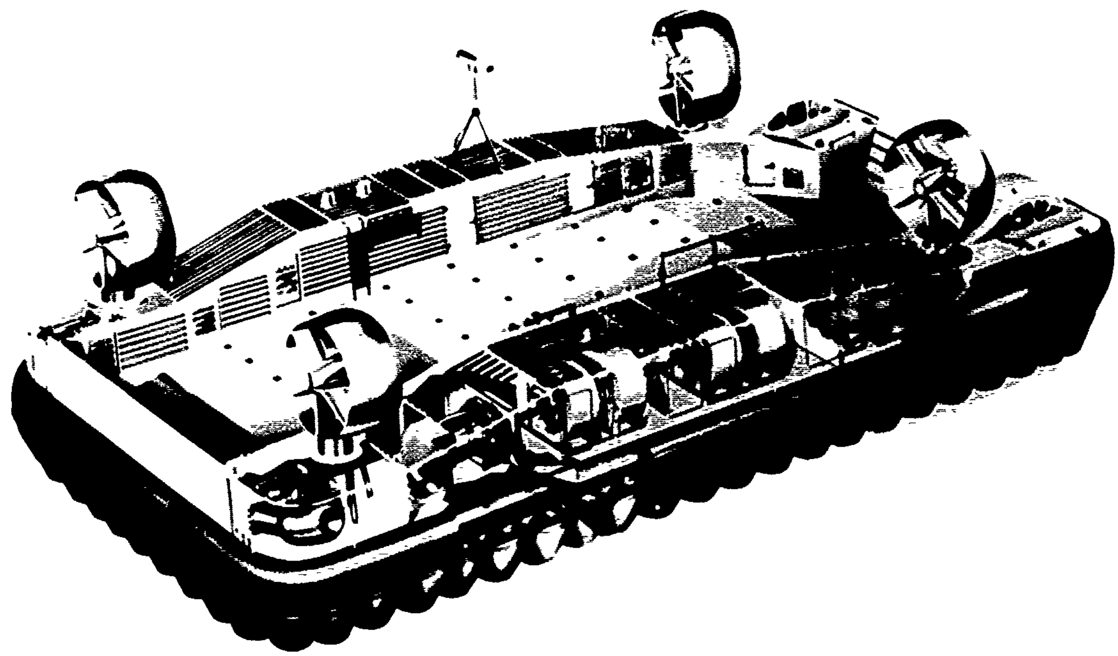
The JEFF craft are designed to be carried in the well deck of an amphibious assault ship such as a landing ship, dock (LSD) or amphibious transport, dock (LPD), Figure 2, and to operate between the ship and the landing area, carrying personnel, equipment, and supplies ashore.

In performance of its mission, the JEFF must repeatedly rendezvous with the LPD/LSD or other supply ship, it will enter the well deck or come alongside to reload, then leave the well deck and return to shore. The most critical stage of this process is docking within the well deck of the LPD/LSD. The on-cushion beam of the landing craft is marginally smaller than the well deck opening, and the relative motion between the JEFF craft and the LPD/LSD may be significant. These motions and the small clearances involved make it inevitable that the JEFF will contact the sidewalls of the well deck.

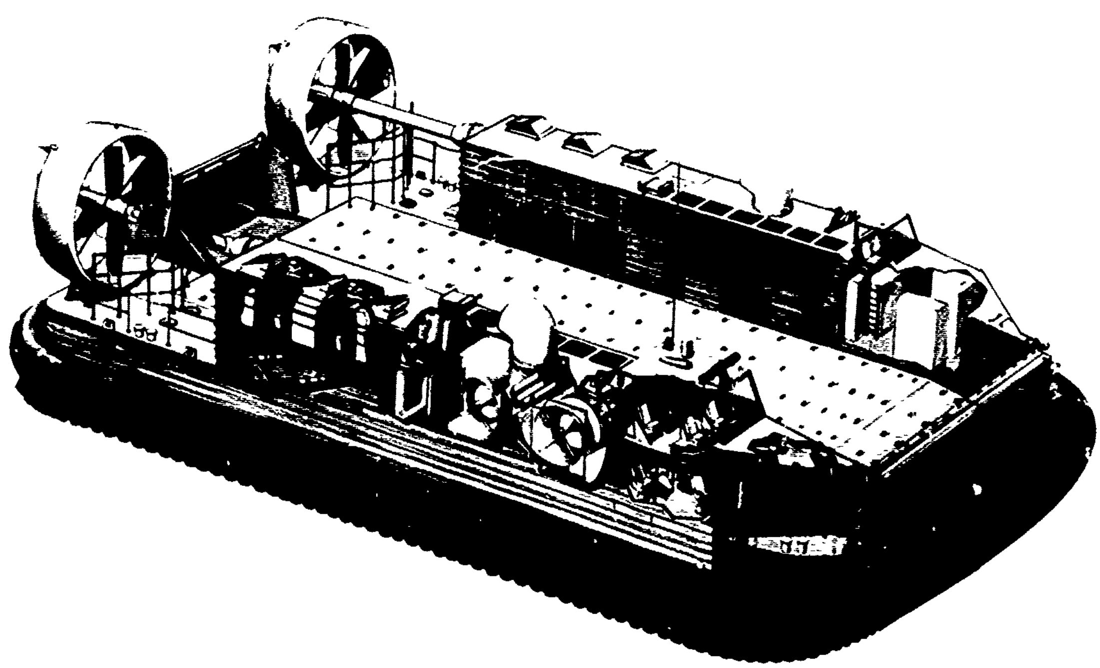
Although the impact velocity of contact during docking is expected to be small, the lightweight nature of the structure and the high craft mass combine to create a situation of moderately high impact energy and low impact resistance forces. This combination requires significant crush deflections to absorb the impact energy. Figure 3 illustrates the energy associated with the loaded JEFF at different velocities. Figure 4 shows the crush deflections required to absorb the impact energies assuming a constant crush force.[2]

The JEFF are protected against impact damage by bumpers located at the four corners of the craft and by the pressurized flexible skirt system. Additional protection is provided by

[2]Gilbert, W.F., "Emperical Design of Peripheral Collision Protection Structure for the Arctic Surface Effect Vehicle," NSRDC Report 4232 (Dec 1973).



JEFF A



JEFF B

Figure 1 – Cutaway Views of the JEFF Craft

TABLE 1 – PRINCIPAL CHARACTERISTICS OF THE JEFF CRAFT

	JEFF (A)	JEFF (B)
Length, Hard Structure Length, Overall (On Cushion) Beam, Hard Structure Beam, Overall (On Cushion) Height, On Cushion Height, Off Cushion	93 Ft., 0 In. 96 Ft., 0 In. 44 Ft., 0 In. 48 Ft., 0 In. 23 Ft., 0 In. 19 Ft., 0 In.	80 Ft., 0 In. 87 Ft., 7 In. 43 Ft., 0 In. 47 Ft., 0 In. 23 Ft., 6 In. 19 Ft., 0 In.
Weight, Design Gross • Light Craft (Crew, Stores) • Fuel • Design Payload • Design Overload Payload	340,000 Lb. 180,000 Lb. 40,000 Lb. 120,000 Lb. 150,000 Lb	325,000 Lb. 166,200 Lb. 38,800 Lb 120,000 Lb 150,000 Lb.
Width, Forward Ramp Width, Aft Ramp Area, Cargo Deck Draft, Off Cushion (Design Wt.)	20 Ft., 0 In. 27 Ft., 4 In. 2,100 Sq. Ft. 2 Ft., 10 In.	26 Ft., 4 In 14 Ft., 6 In. 1,740 Sq. Ft. 3 Ft., 4 In.
Engines Installed Power, Total	6 AVCO Lycoming TF-40 16,800 SHP	6 AVCO Lycoming TF-40 16,800 SHP
Propulsors	4 Reversible Pitch Shrouded Propellers of 89.5 In Diameter	2 Shrouded Reversible Pitch Propellers of 141 In. Diameter, 2 Bow Thrusters (From Lift Fans)
Lift Fans	8 Single Centrifugal Fans of 48 In. Diameter, 1,600 CFS Per Unit at 170 PSF	4 Double Centrifugal Fans of 60 In. Diameter, 4,750 CFS Per Unit at 170 PSF
Control System	4 Rotatable Propulsors, Artificial Feel, Fly-By-Wire Control, Yaw Rate Feedback Auto Pilot	2 Rotatable Bow Thrusters, 2 Aerodynamic Rudders, Artificial Feel, Fly-By-Wire Controls
Skirt System	Looped Pericell, 5 Ft. High	Bag/Finger with Stability Trunks, 5 Ft. High
Structure	Welded 5086 Aluminum Corrugated Sheet, GRP Crew Cabin Housing	Welded 5086 Aluminum "Hat" Stiffened Sheet, Balsa Core Superstructure Decking, Riveted 6061-T6 Truss Core Cargo Deck
Design Performance with 120,000 Payload on 100°F Day		
Speed (Sea State 2 and 25 Knot Headwind)	50 Knots	50 Knots
Range (Sea State 2 and 25 Knot Headwind)	200 N. Miles	200 N. Miles
Surf Capability Maximum Slope	8 Ft. Plunging Surf 11.5%	8 Ft. Plunging Surf 13%

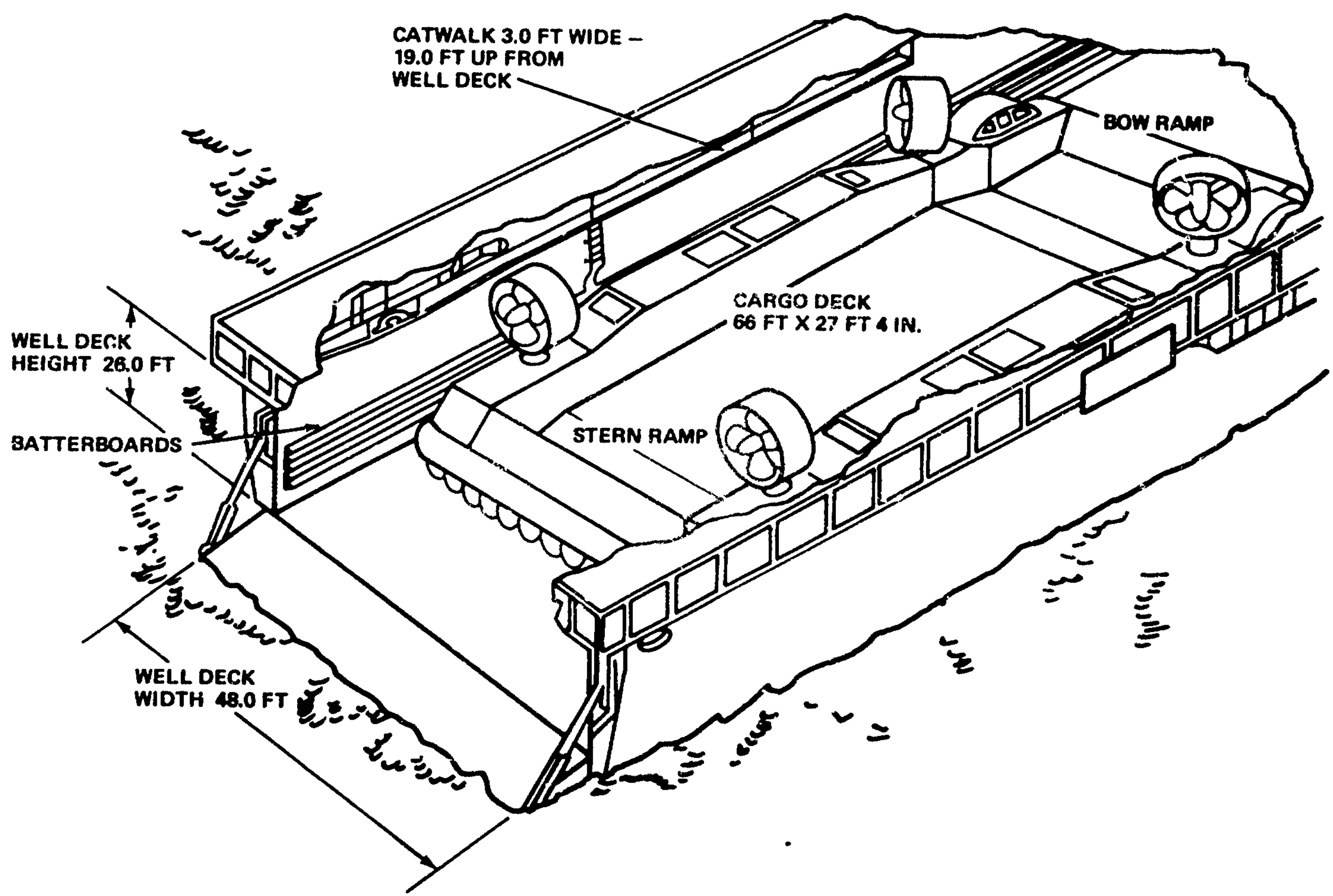


Figure 2 – Docking of the JEFF With the LPD/LSD

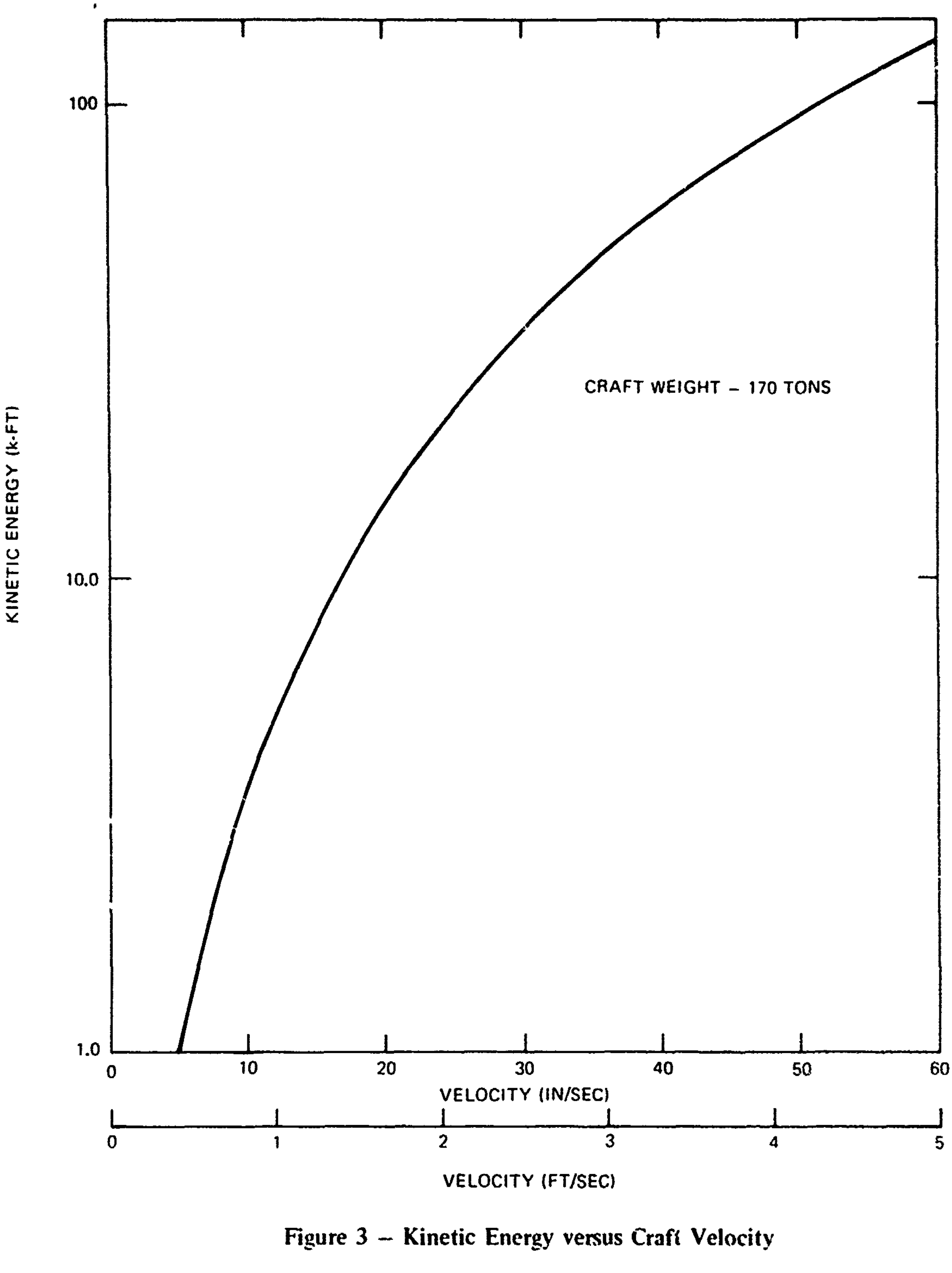


Figure 3 – Kinetic Energy versus Craft Velocity

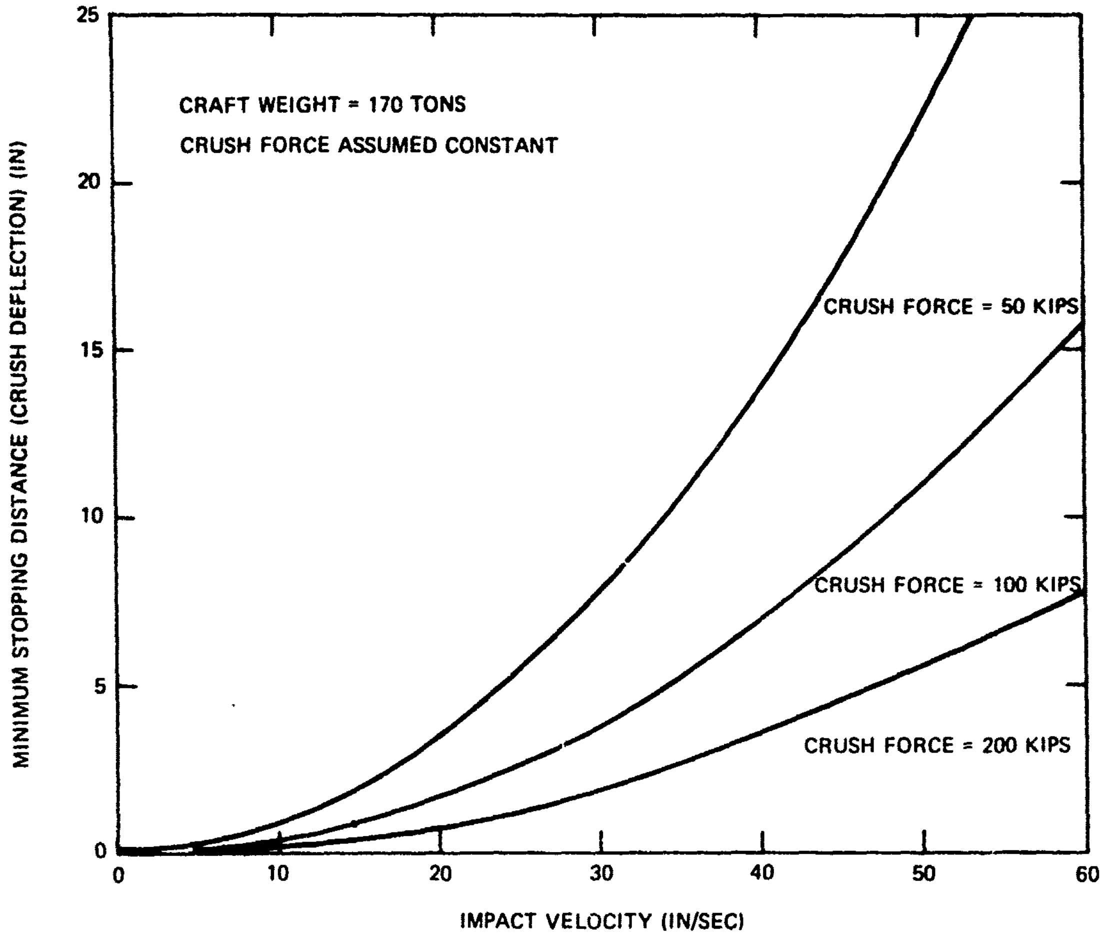


Figure 4 – Minimum Crush Deflection versus Impact Velocity

fenders on the LPD/LSD. As the craft makes contact with the well deck, the bumpers and flexible skirt system deform, absorbing energy and modifying the JEFF rigid body motions. In some cases, the deformation of the protective systems is high enough to allow contact of the hard structure and the well deck entrance corner.

Deformation of the bumpers, pressurized skirt systems, and even the hard structure does not necessarily result in degradation of craft performance. The extent of the damage which can be sustained without reduction of craft capabilities depends on the location and the amount of deformation. For example, if the hard structure deformation is elastic, the structure returns to its original condition and configuration following the impact. her-more, if no operating equipment contacts the deflected structure, no degradation e equipment is likely. Even when plastic deformation occurs, the craft will still be ole of performing its mission provided (1) that the damage is not in a critical region where the deflected structure interferes with the operation of the craft and (2) that the watertight boundaries of the craft are not compromised. Plastic deformation of the hard structure is certainly to be avoided, however; the JEFF must repeatedly dock with the LPD/LSD to perform its mission, and successive impacts in the same region could cause progressively greater damage until the craft is finally disabled.

This study was concerned with the consequences of docking impacts. What are the craft motions? Does structural damage occur and is it serious enough to disable the craft? How extensive is the damage and how effective are the craft protection systems? What operational method of docking will minimize impact damage?

The approach used in this study of craft vulnerability to impact was to analyze the docking process by using motions data available from small-scale, towed-model studies[3] and to determine the likely forms and magnitudes of the collision parameters. Probable collision locations, velocities, and craft orientations were analyzed. The prototype craft under construction were chosen for analysis, namely, the Aerojet Corporation JEFF(A), and the Bell Aerospace Corporation JEFF(B). The structural designs of the two craft were analyzed to determine their load-deflection characteristics at potential impact points. The locations of such critical items of equipment as turbines and fans were determined and allowable hard structure deflections defined. The load-deflection characteristics of the skirt were defined on the basis of cushion pressure and skirt shape. A computer program (CUSH) was written to calculate the flexible skirt load deflection functions for various impact locations and yaw angles.

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[3]Anderson, S.R., "Study of Interaction between Mothership and Amphibious Air Cushion Vehicle during Loading or Unloading," NSRDC T&E Report 418-H01 (Feb 1971).

Another computer program (DOCK) was written to calculate the rigid body motions of the JEFF and the crush deflections resulting from a docking collision initiated at a specified location and at a given initial velocity. The program is basically a three-degree-of-freedom, rigid-body motions program, but local deflection at the point of contact is permitted and the loading on the craft is defined by the local deflection and load-deflection functions. Sliding forces are defined as well as other forces which may develop, e.g., forces from the craft-handling system, secondary collision forces when another point on the JEFF comes into contact with the well deck sidewall, and bumper crush forces. These forces are all discussed in some detail in following sections of the report. Many options are built into the computer program to allow analysis of a number of impact conditions. Some of the options have not been extensively used in this study, but they do enhance the value of the program as an analytical tool.

This report documents and presents the scope of the study; it includes a description of the mathematical models for the JEFF(A) and the JEFF(B), a development of the roll analysis theory, and the results of the collision studies using computer program DOCK. A discussion of the docking collision vulnerability of the two JEFF craft is also presented together with a general discussion of the types of well deck entries least likely to cause damage.

SCOPE OF THE STUDY

It is clearly not feasible to investigate every possibility for collision when a JEFF craft docks with an LPD/LSD. Instead, an attempt is made to cover the probable range of likely collisions. These are listed in Tables 2 and 3 for the two configurations. Most well deck entries will be made after a JEFF craft has returned from the landing zone following discharge of cargo and with all systems operational; many other forms of entry are possible, however, and some of these are investigated. Cases studied include: two entry modes (on-cushion and off-cushion), two displacement modes (loaded and unloaded), and three types of impact, namely, bow (single initial contact location), side (three initial contact locations), and rolled (single initial contact location).

The scope of the study is defined: bow and side impact, rolled impact, and multiple impact.

BOW AND SIDE IMPACT

Both bow and side collisions are possible; see Figure 5. Bow collision is defined as the impact of the bow of the JEFF with the transom of the LPD/LSD. Side collision is defined

TABLE 2 – DOCKING IMPACTS INVESTIGATED FOR THE JEFF(A)

(The total number of cases does not equal the number of possible combinations because not all parameters are varied independently)

Parameter	Cases	No. Cases
Craft	JEFF(A)	1
Entry Mode	On-Cushion Off-Cushion	2
Displacement	Loaded Unloaded	2
Collision Location	Bow (one location) Side (three locations) } Single Collision	4
Velocity	Side Collision V = 60 in/sec Bow Collision V = 30 in/sec	2
Velocity Attack Angle, deg	ϕ = 0, 5, 15	3
Yaw Angle, deg	θ = 0 (when $\phi \neq 0$) θ = 1, 3, 5	4
Rolled Impact (side collision only off-cushion) deg	α = 1, 3, 5, 8 One Location, off-cushion V = 20 in/sec ϕ = 90, $\theta \neq 0$	4
Total No. of Cases	200	

TABLE 3 – DOCKING IMPACTS INVESTIGATED FOR THE JEFF(B)

(The total number of cases does not equal the number of possible combinations because not all parameters are varied independently)

Parameter	Cases	No. Cases
Craft	JEFF(B)	1
Entry Mode	On-Cushion Off-Cushion	2
Displacement	Loaded Unloaded	2
Collision Location	Bow (one location) Side (three locations) (On-Cushion only) } Multiple Collisions	4
Velocity	Side Collision V = 60 in/sec Bow Collision V = 30 in/sec	2
Velocity Attack Angle, deg	ϕ = 0, 5, 15	3
Yaw Angle, deg	θ = 0 (when $\phi \neq 0$) θ = 1, 3, 5	4
Rolled Impact (side collision only off-cushion) deg	α = 1-, 3-, 5-, 8-deg roll angles V = 20 in/sec, ϕ = 90, $\theta \neq 0$ deg	4
Total No of Cases	134	

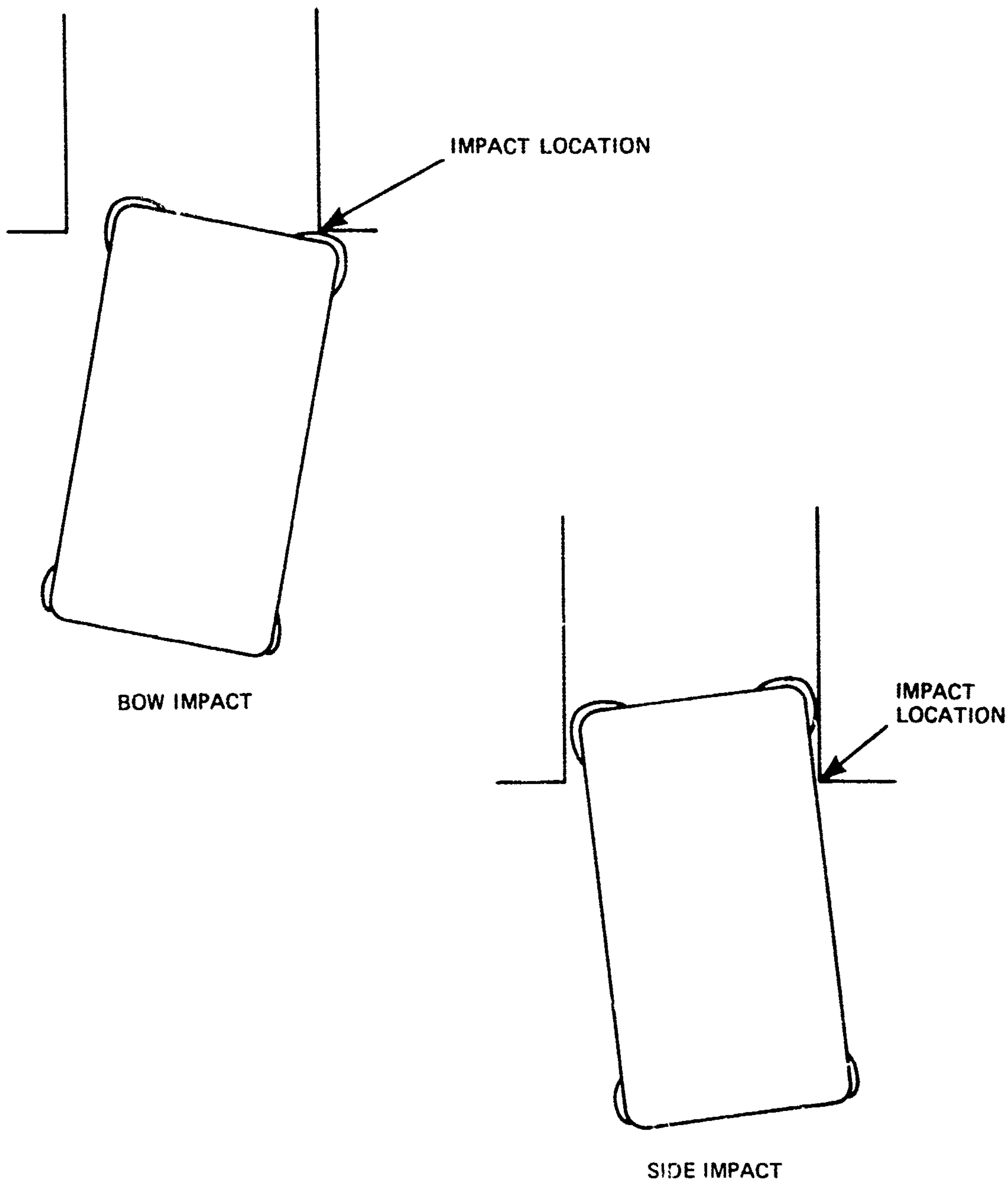


Figure 5 – Definition of Bow and Side Collisions

as impact of the side of the JEFF with the well deck entrance corner of the LPD/LSD. Fenders on the transom of the LPD/LSD will reduce the severity of a bow collision and transform most docking impacts to side collisions.

The initial relative velocities of the JEFF to the well deck were selected as reasonable estimates of the expected impact velocities; they are consistent with the energy levels to which the craft bumper system is designed. Since a bow collision necessarily involves more lateral displacement of the JEFF from the LPD/LSD centerline than does a side collision, the misalignment should be detectable early in the docking process and corrective measures, including speed reduction, taken. At first, it might appear that off-cushion velocities should be lower, but it must be remembered that the velocity associated with impact is total relative velocity between the craft and the well deck. A craft in the displacement mode (off-cushion) is perhaps even more susceptible to motion by wave action than when on-cushion.

The relative velocity vector is not necessarily aligned with the centerline of the well deck. The "velocity attack angle" describes the orientation of the relative velocity vector from the well deck centerline orientation. Three velocity attack angles were chosen for study. 0, 5, and 15 deg. The last angle is probably somewhat extreme and the 5-deg orientation more common.

The orientation of the JEFF relative to the well deck is important, especially for side collision impacts. The yaw angle defines the initial rotation of the JEFF centerline relative to that of the LPD/LSD. Four yaw angles were chosen for investigation: 0, 1, 3, and 5 deg. The 5-deg yaw is considered high and the 1- to 3-deg yaws more common.

The location of the point of initial impact influences the rigid body motions of the craft during collision since the location of the impact defines the structure involved and this, in turn, defines the load-deflection function. Also, the location of the impact point relative to the center of gravity (CG) of the JEFF is important in defining the degree of rigid body rotation during collision.

Bow impacts were investigated for a single initial point of impact. The athwartship location of the bow impact point is just inboard of the outboard extremity of the hard structure. Three initial impact locations were considered for side collision cases. Since a side collision is more of a glancing impact, the possibilities for the location of the point of initial contact are more numerous. The three locations selected for side collision investigation were (1) just aft of the bow, (2) just forward of the location of the CG, and (3) midway between these two locations. These three locations allowed a comparison of the influence of the initial impact location.

ROLLED IMPACT

Rolled impact is the side collision impact of an initially rolled JEFF. Such impacts are potentially more damaging because less force is required to crush the JEFF structure at the top of the framing than at the machinery deck (main deck) level (where most of the impact loads are taken in the rest of the collision cases). Figure 6 illustrates the basic structure and framing of the two craft. The study investigated the ability of the craft to roll as a rigid body under the range of impact loads possible at the top of the frame.

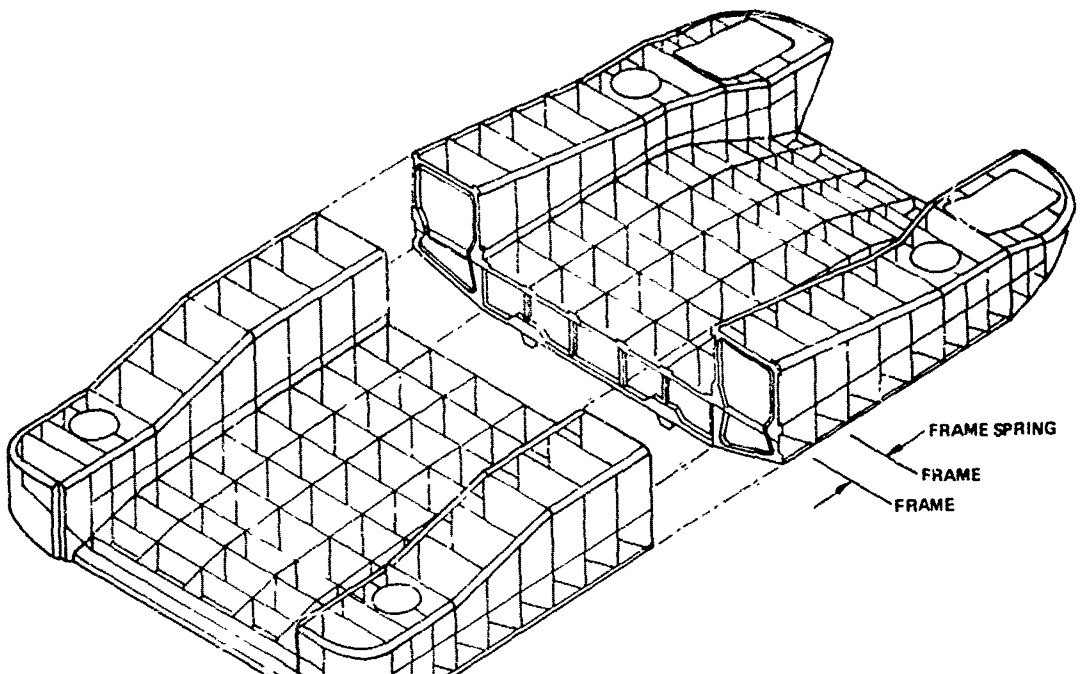
MULTIPLE IMPACT

One difference between the cases studied for the two configurations is that collisions investigated for the JEFF(A) were single impact cases whereas motion was allowed to continue for the JEFF(B) following the initial impact. In the JEFF(A) single impact cases, when the point in contact with the well deck corner stopped crushing, the collision was considered complete and the computer run terminated. Actually, the point in contact stops crushing either (1) when all the energy in the normal direction has been absorbed (as happens most often in bow collisions) or (2) when a combination of absorbed energy and rigid body rotation brings the normal velocity of the contact point to zero. When the latter happens, the collision ends at the point of contact, but the remaining motion of the craft may carry it on to collide at a later time with a different point on the craft. This is termed secondary collision. The location of the secondary collision point is often near the last point of contact, but it can sometimes be distant.

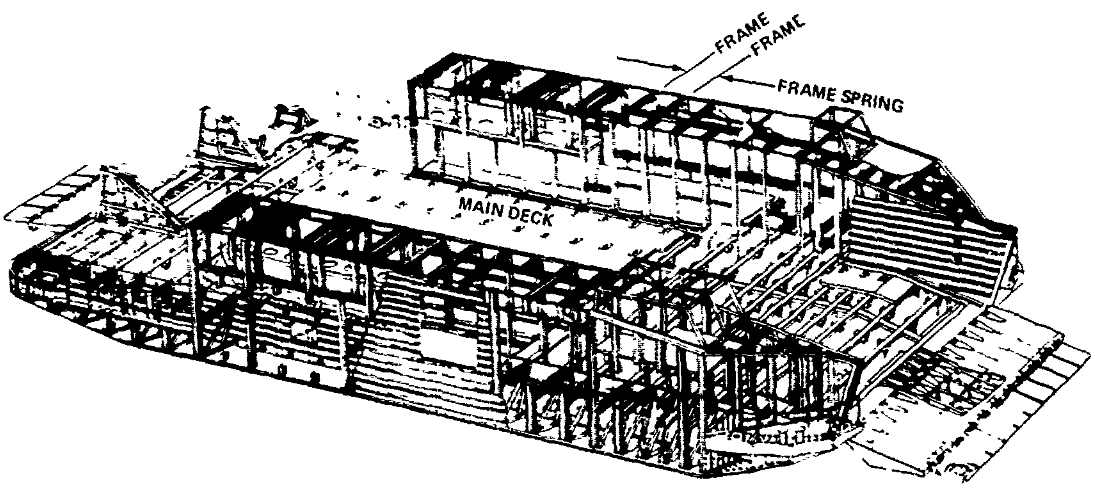
SCOPE SUMMARY

The full matrix of parameters investigated for the two configurations have been indicated in Tables 2 and 3. The major difference is that off-cushion, side-collision entries were not investigated for the JEFF(B) in order to extend the study to include rolled impact. Since the two craft are very much alike, an adequate comparison of their impact vulnerability can be achieved from the remainder of the cases investigated.

The combination of various options for each of the parameters investigated in the study resulted in a total of 200 cases for the JEFF(A) and 134 cases for the JEFF(B). In addition, another 132 cases were concerned with off-cushion side collisions where the bumper was dominant and more realistically modeled.



JEFF A



JEFF B

Figure 6 – Structure and Framing of the JEFF Craft

Obviously, this mountain of data cannot be totally presented in this report. Instead, the basic results, trends, and important parametric influences have been extracted for presentation. The remaining data have been cataloged and retained by the author and are available for additional study.

COLLISION FORCES

Although the normal crush forces are defined by the load-deflection functions for the initial point of contact, the surface forces are defined through a friction coefficient. Crush forces are related to surface forces by

$$F_s = \mu F_{cr} \tag{1}$$

where F_s = surface force

F_{cr} = crush force

μ = coefficient of friction

Except for locations on the bumper, the coefficient of friction is assumed to be equal to 0.3. This value may be somewhat high if the surface force is actually only sliding friction. However, when the cushion deflects, the corner of the well deck is partially imbedded in the deflected air bag and the longitudinal translation of the craft is resisted by higher forces as the conformed skirt material is forced past the well deck corner. The magnitude of these forces is not known. Several computer runs were made at varying coefficients of friction to study their influence on crush deflections and rigid body motions. For bow collisions, it was found that the coefficient of friction had little effect on either crush deflection or rigid body motion. For side collisions, the friction coefficient had no effect on crush deflection, but it did influence surge velocity. In a side collision, however, surge velocity is tangentional to the impact surface rather than normal to it and therefore has little effect on impact damage.

Although the value of the friction coefficient selected is not important in defining crush deflections or normal impact damage in a docking collision, it is important in determining the likelihood of damage to the skirt system. The skirt drag forces increase in direct proportion to the friction coefficient. When these forces exceed the shear or tension capability of the skirt or skirt hinges, either the skirt tears or the hinges part. This type of damage is not investigated here since insufficient data are available on the actual friction coefficient. The friction forces resulting from a drag coefficient of 0.3 were calculated within the scope of this study, however, and may prove useful in determining the vulnerability of the JEFF skirt system.

The friction coefficient on the surface of the bumper was defined as 0.1. When the bumper deflects, it does so over its entire length. There is no differential deflection as with skirt deflection and therefore no high drag when the well deck entrance corner is partially imbedded in the bumper. For this reason, the friction coefficient on the bumper was taken to be less than that on the skirt system.

It should be noted that some combinations of the conditions investigated are not operationally realistic. For example, in an off-cushion side collision with an initial yaw angle of zero, the bumper would already have totally crushed when "initial" contact is described as hard structure contact. It is certainly possible for the "initial conditions" to occur, but the collision actually starts before the designated initial impact. Nonetheless, these investigations are useful in that they allow a more complete determination of the role of other parameters in impact damage prediction. In order to more realistically assess docking impact damage for these initial conditions, however, a second set of computer runs were made wherein initial contact on the bumper was defined where it would actually occur. Both sets of data are reported.

ENERGY-ABSORBING BUMPERS

Bumpers are located on the bow and on the forward and aft portions of the side structure. Figure 7 shows bumper location relative to the hard structure and the flexible skirt system. Based on contractor data, the bumper is assumed to be 10 in. thick and capable of crushing at a constant 50-kip crush force for 7.5 in. after a linear elastic range of 0.5 in. After crushing to 8.0 in., the bumper is assumed to "bottom" and its crush force is assumed to rise linearly to that of the structure supporting it. The backup structure is assumed to be capable of supporting the crushing bumper without plastic deformation. The bumper force deflection profile is illustrated in Figure 8.

OPPOSITE CORNER IMPACT

Opposite corner collision (Figure 9) can also occur during the docking process. This happens when the craft rotation is sufficient to cause the bow corner on the opposite side from the collision contact point of the craft to contact the opposite wall of the well deck. This means that for single impact cases, opposite corner contact occurs simultaneously with impact on the collision side; it may occur separately for multiple impact cases where the JEFF is allowed free flight between collision side impacts. Opposite corner collision was investigated

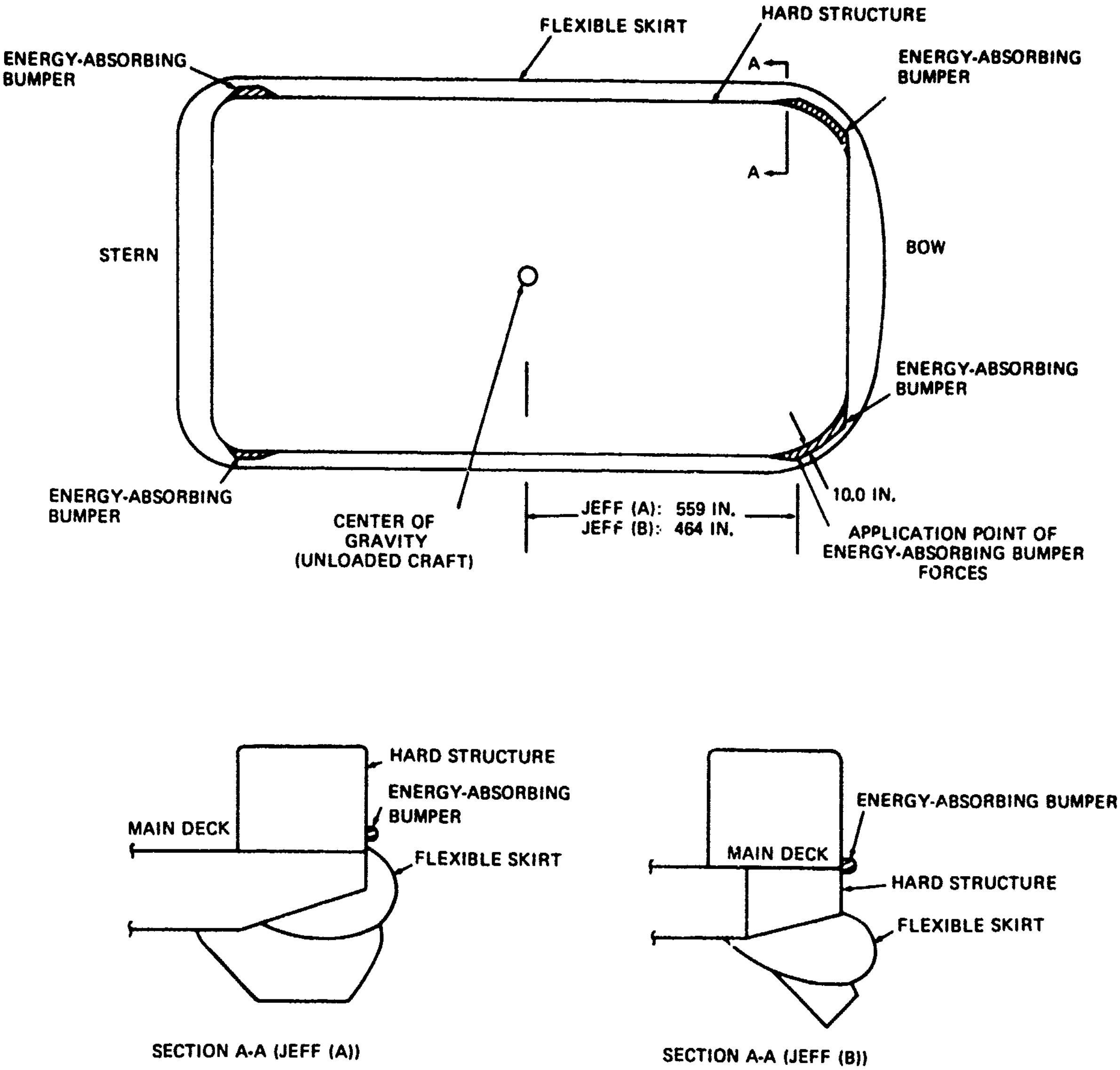


Figure 7 – Location of Energy-Absorbing Bumpers

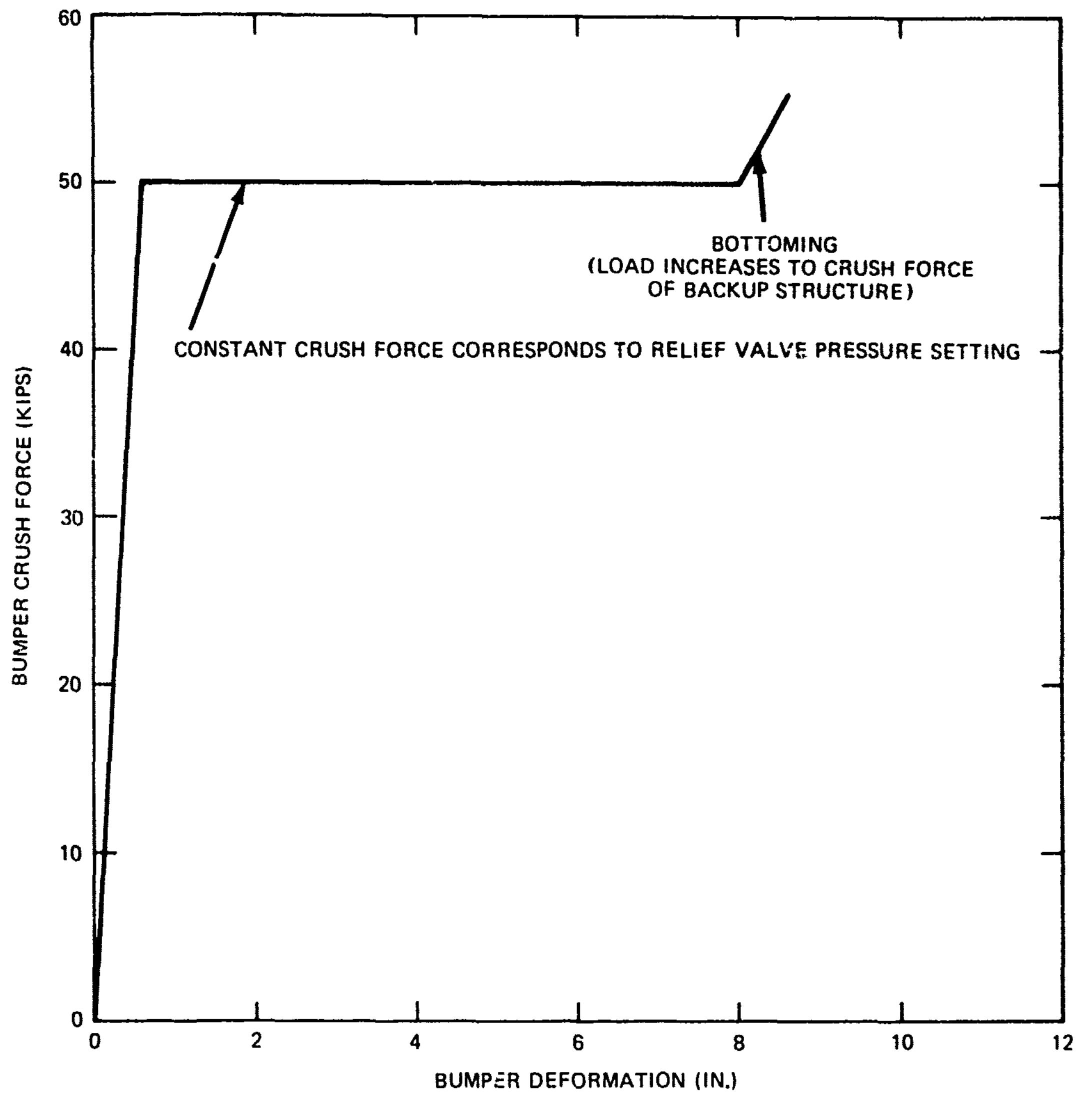


Figure 8 – Load-Deflection Function of Energy-Absorbing Bumpers

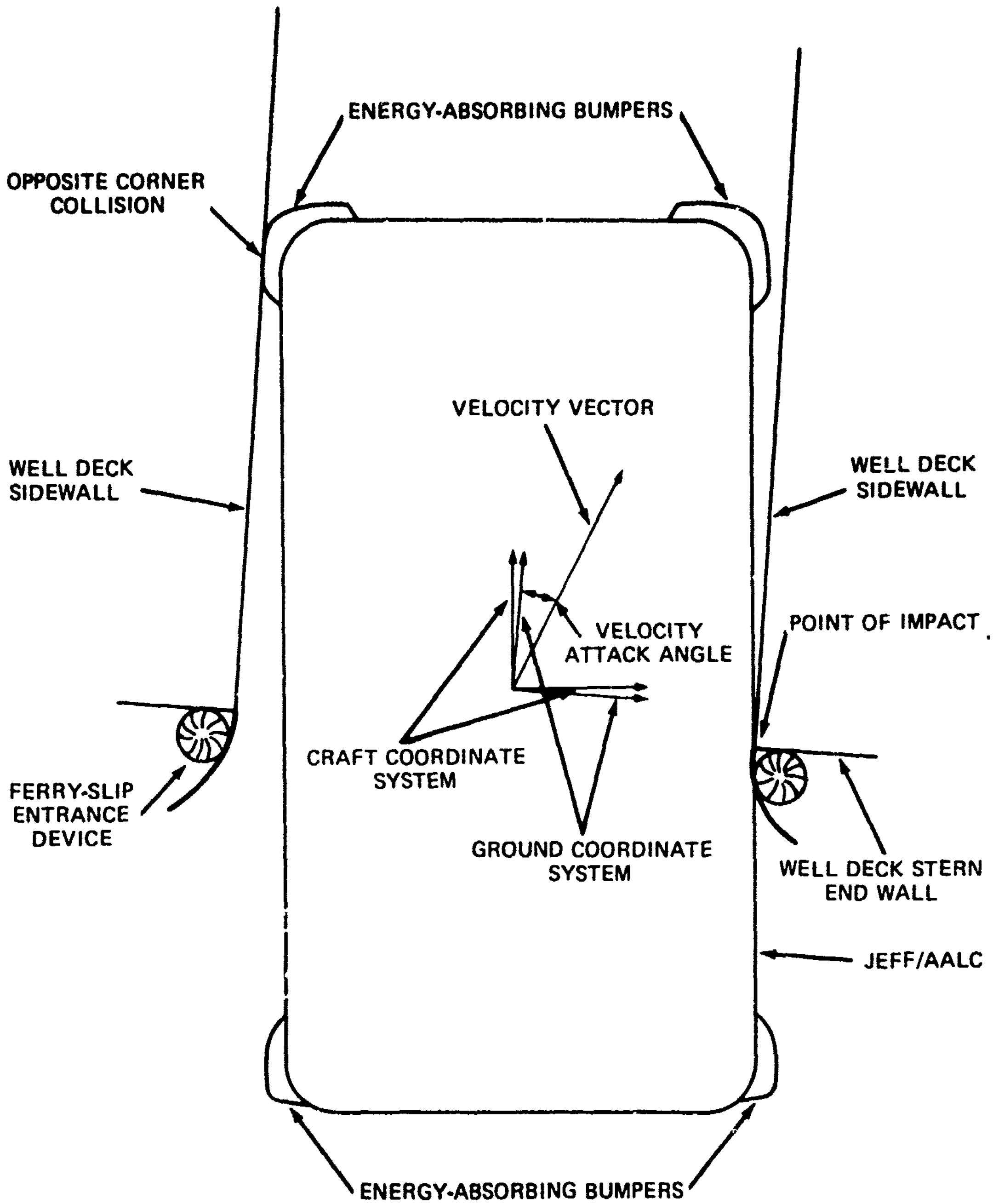


Figure 9 – Opposite Corner Collision during Docking

for all collision cases; when it did occur, its impact forces were defined by a separate load-deflection function which included cushion (if on-cushion entry), bumper, and hard structure deformation.

AMPHIBIOUS IN-HAUL DEVICE

Figure 10 illustrates the design of an amphibious in-haul device (AID) intended for installation on the LPD/LSD to enable the JEFF to be towed into the well deck. A set of lines (tow line, restraining line, and braking line) to each side of the JEFF attach to a carriage which moves on a rail mounted high on the sidewalls of the well deck.

The AID craft-handling system forces were not modeled for this study, but the capability to include them in the analysis has been developed and built into the computer program. The cable forces would, of course, not be effective until the craft was significantly into the well deck. This means that cable forces would not be effective for bow collisions since the craft is not then within the well deck. Also, when the JEFF is significantly into the well deck, the threat of docking collision damage is greatly reduced. There is also serious question regarding the ability of the cable tow-in system to effectively reduce collision motions because the cables which connect the chocks on the JEFF to the overhead tow-in rail in the well deck are oriented at such an extreme vertical angle.

Even if the AID craft-handling system were capable of restraining the bow of the JEFF in the center of the well deck, the stern could swing around and cause side structure collision with the well deck entrance corner. Admittedly, these impacts may be slightly less severe than without the cable tow-in system.

DOCKING COLLISION MODELS

The two JEFF craft were mathematically modeled for docking collision analysis by using computer program DOCK. The data included craft size, translational and rotational inertias for motions in the horizontal plane, a description of the energy-absorbing bumper and its load-deflection curve, a definition of the initial impact locations, and the load-deflection functions for the initial impact locations including the cushion load-deflection curves. Many of the items change with craft displacement and depend on whether it is on- or off-cushion.

The two craft studied differ in most of their mathematical modeling definitions. The well deck with which the JEFF must dock is common to both, however. The mother ship is either the LPD or the LSD; both have the same well deck width (48.0 ft) between the batterboards on the inboard side of the wing walls (see Figure 2).

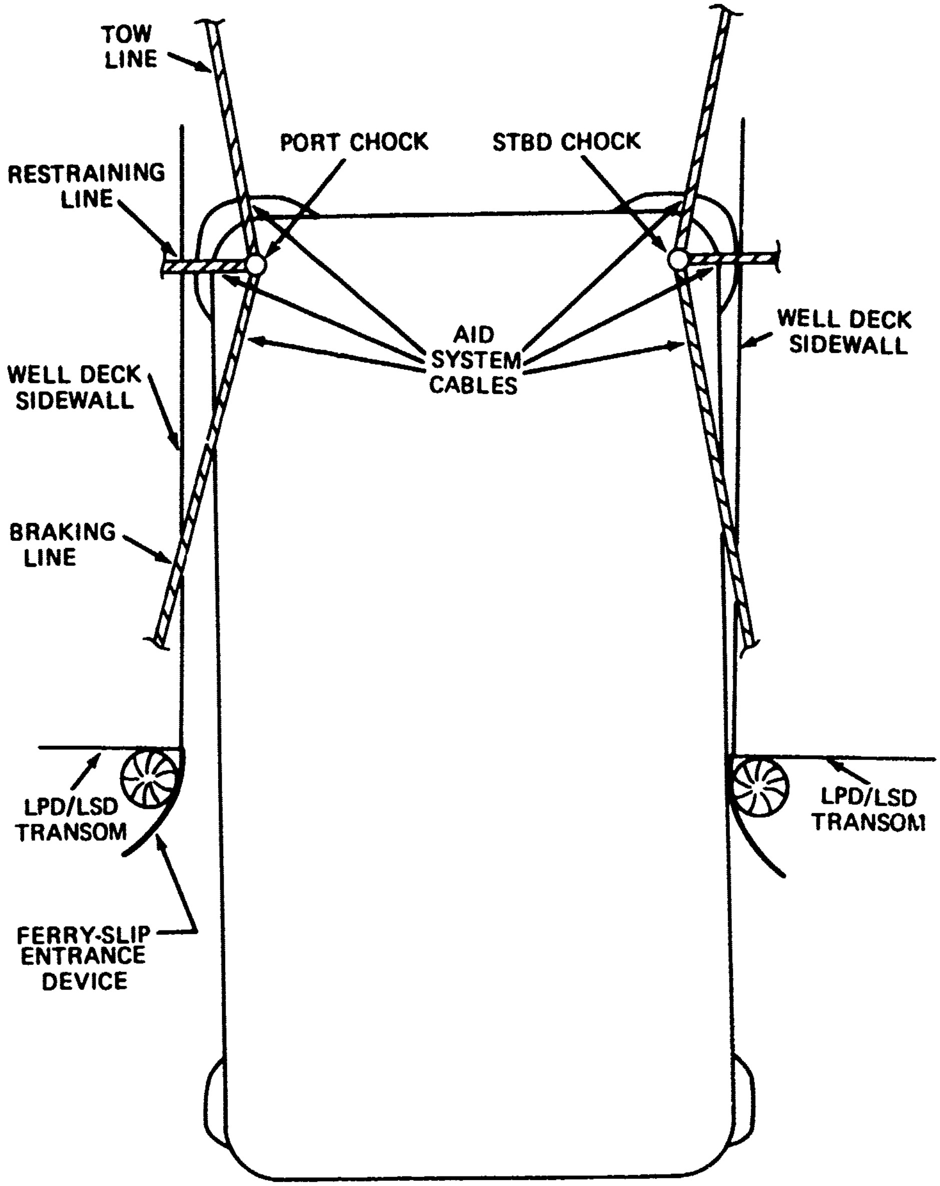


Figure 10 – Amphibious In-Haul Device

MATHEMATICAL MODELS OF THE JEFF CRAFT

The size of the JEFF craft were defined as follows:

	JEFF(A)	JEFF(B)
On-Cushion:		
Length	1153.6 in. (96.2 ft)	1051.5 in. (87.7 ft)
Beam	574.2 in. (47.85 ft)	564.0 in. (47.0 ft)
Off-Cushion:		
Length	1103.9 in. (92.0 ft)	960.0 in. (80.0 ft)
Beam	528.0 in. (44.0 ft)	516.0 in. (43.0 ft)

Since the well deck width is 48.0 ft or 576.0 in., the on-cushion JEFF(A) has a total beam clearance of 1.8 in., and the on-cushion JEFF(B) has a total beam clearance of 12.0 in. Contact of the on-cushion craft with the well deck sidewall during docking is certain.

The mass and yaw moment of inertia depend on whether or not the craft is loaded. The cargo load not only changes these parameters, but it also shifts the location of the CG. The cargo considered is the 120,000-lb design payload, and uniform cargo distribution is assumed. The mass, yaw moment of inertia, and CG locations for loaded and unloaded, on-cushion and off-cushion, JEFF(A) are included in Table 4.

The off-cushion inertia values reflect the effect of the "added mass" of water which moves with the craft when it is accelerated in the off-cushion mode. The amount of added mass which acts with JEFF craft was determined from NSRDC model test data.[4,5] The values used were intended only as an approximation of the actual added mass associated with JEFF craft. The model test data in this area are not considered entirely accurate because of inability to properly scale the flexibility of the model skirt system. However, since there were no full-scale data, the model data were the best available, and the added mass was defined from them for the mathematical model. Since the JEFF behavior in the confines of a flooded well deck may be somewhat different from that in the open sea, it may be desirable to investigate these effects in more detail when full-scale data are available.

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[4]Fein, J.A., "Horizontal Plane Static and Dynamic Stability Characteristics of the JEFF(A) Amphibious Assault Landing Craft," NSRDC Evaluation Report 467-H-04 (Mar 1973).

[5]Fein, J.A., "Horizontal Plane Static and Dynamic Stability Characteristics of the JEFF(B) Amphibious Assault Landing Craft," NSRDC Evaluation Report 467-H-05 (Apr 1973).

TABLE 4 – MASS, INERTIA, AND CENTER OF GRAVITY LOCATIONS FOR THE JEFF CRAFT

JEFF(A)

On-Cushion:	Loaded	Unloaded
Distance from Bow to CG, in.	542.2	566.2
Mass, lb-sec^2/in.	880.0	492.0
Yaw moment of inertia, lb-sec^2-in.	7.95×10^7	6.47×10^7
Off-Cushion:	**Loaded**	**Unloaded**
Distance from Bow to CG, in.	542.2	566.2
Mass, lb-sec^2/in.	1341.0	953.0
Yaw moment of inertia, lb-sec^2-in.	17.77×10^7	16.29×10^7

JEFF(B)

On-Cushion:	Loaded	Unloaded
Distance from Bow to CG, in.	491.9	470.9
Mass, lb-sec^2/in.	852.0	464.0
Yaw moment of inertia, lb-sec^2-in.	6.65×10^7	4.54×10^7
Off-Cushion:	**Loaded**	**Unloaded**
Distance from Bow to CG, in.	491.9	470.9
Mass, lb-sec^2/in.	1298.0	910.0
Yaw moment of inertia, lb-sec^2-in.	14.85×10^7	12.75×10^7

LOCAL LOAD-DEFLECTION MODELS OF THE JEFF CRAFT

The specific energy-absorbing characteristics of bumpers chosen for the JEFF(A) and the JEFF(B) were not finalized when this study was conducted. Enough preliminary work had been done, however, to define a representative bumper for this investigation. Both craft were assumed to have the same bumper system installed, and the structure to which the bumper is mounted was assumed to be capable of carrying the crush loads of the bumper. The bumper was envisioned as either a pneumatic or extruded rubber device. The assumed dimensions and locations of the bumpers are shown in Figure 7. The bumper does not protect the entire periphery of the craft. It wraps around the bow corner and extends for a short distance along the hard structure on the side of the craft. A short side bumper is located at the stern. The bumper depth or dimension in the potential crush direction was assumed to be 10.0 in. and the crush force as 50 kip. The load-deflection curve for the bumper is shown in Figure 8.

Of course to be effective in protecting the docking JEFF, the bumper must come in contact with the sidewall of the well deck. It is interesting to note that when the bumper is located far forward on the side structure of the craft, it is possible for the off-cushion JEFF to impact the well deck corner without touching the energy-absorbing bumper. Figure 11 illustrates the range of craft orientations and impact points where the bumper is ineffective. This phenomenon is modeled in the computer program.

Figure 12 illustrates the initial impact locations for the two craft. Each craft was investigated for initial impact at a single point on the bow hard structure, near the starboard periphery, and at three locations along the starboard side: near the bow, near the CG, and at a location between those two. Note, however, that the impact locations on the JEFF(B) do not always correspond to those on the JEFF(A). When collision damage is compared for the two craft, care must be taken to ensure that only similar impact locations are used. Bow collision was assumed to be on the hard structure for the JEFF(A) where the bow ramp and associated structure protrude forward of the bow seal. Although the bow seal does protrude slightly beyond the hard structure at the impact location in the case of the JEFF(B), the protection offered is minimal. The curvature of the craft at the corner is high and bag displacement by the well deck corner is insignificant. Moreover, the amount of protrusion of the bag is also small. The energy absorption of the bow seal on the on-cushion JEFF(B) was therefore ignored. For docking collision considerations, the JEFF was considered as symmetric about the centerline and therefore vulnerability was considered to be identical on the port and starboard sides.

The load-deflection functions at the initial impact locations were computed for the hard structure and cushion of the JEFF. The portion of the load-deflection function for the

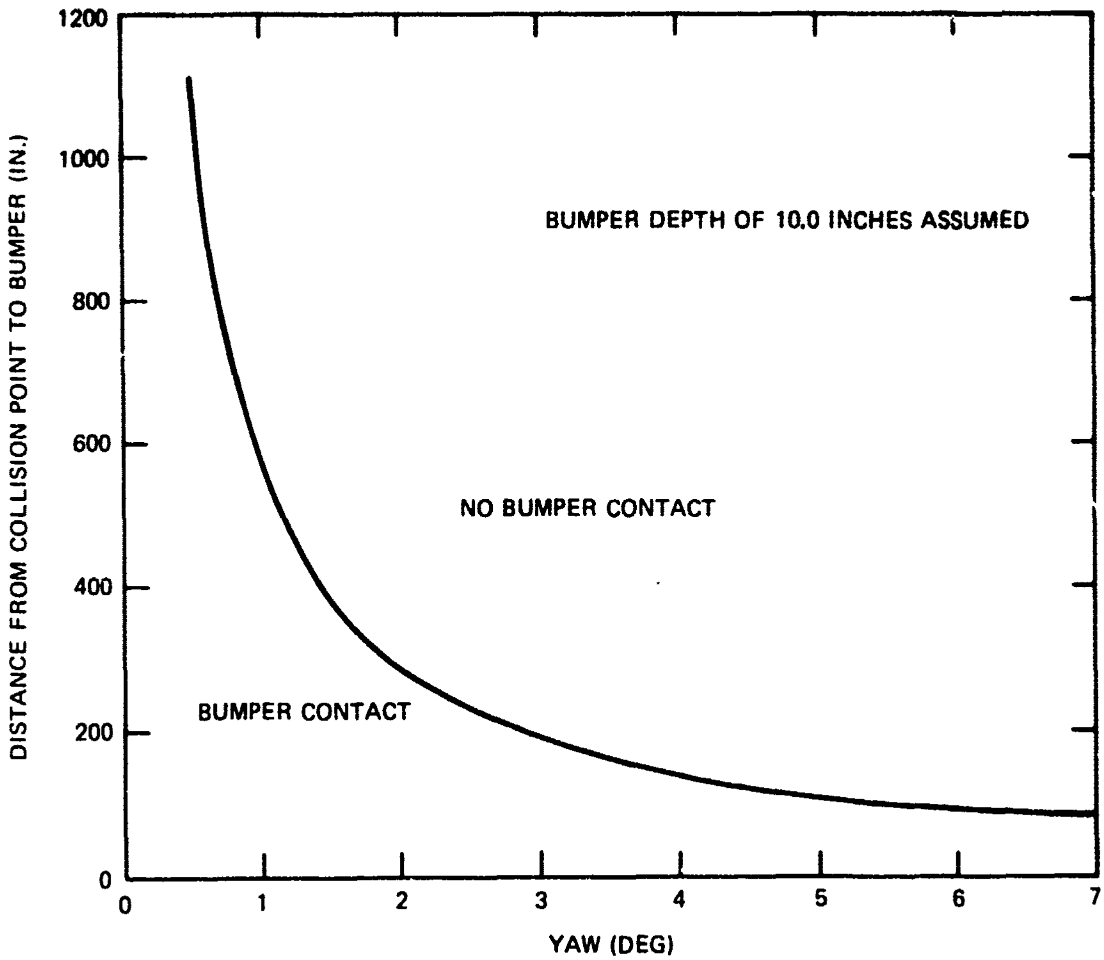
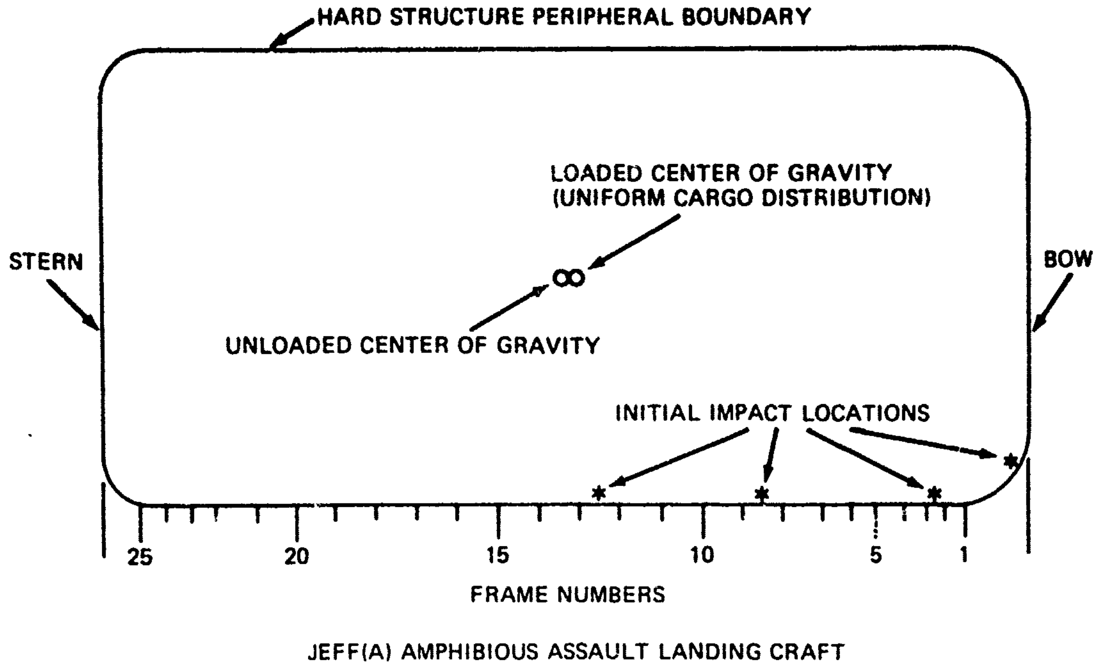


Figure 11 – Influence of Collision Geometry on Bumper Effectiveness



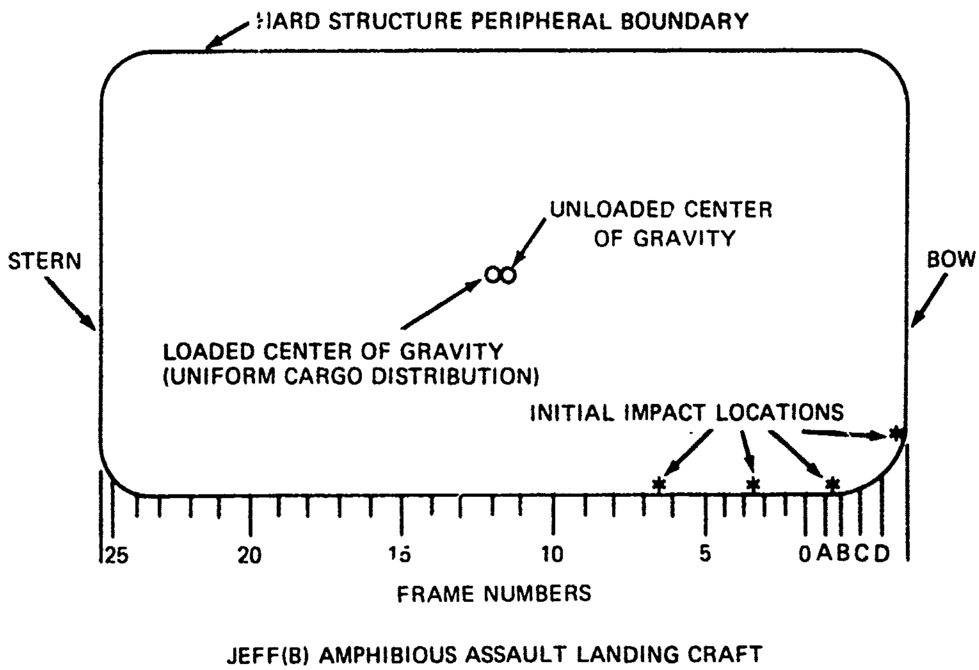


Figure 12 – Initial Impact Locations for the JEFF Craft

cushion was calculated by simply displacing the volume of the cushion* as the well deck sidewall indents the cushion. As the volume of the plenum decreases, the pressure rises. This pressure loads the sidewall and the craft at a load defined by the pressure over the "footprint" area of the cushion on the well deck sidewall. The calculation of this load was somewhat complicated since the air bag has a curved surface and the well deck sidewall penetrates the cushion at various yaw angles (further complicating the assessment of footprint area). Furthermore, the calculation must be made at incremental deflections to fully define the load-deflection function of the cushion. As already indicated, a short computer program (CUSH) was written to enable this set of calculations to be made rapidly. Figure 13 presents the peak crush forces for the JEFF cushions at various yaw angles and impact locations. The JEFF(B) cushion loads were lower than those of the JEFF(A) principally because of the initial impact locations selected. If identical lengths of air bags are compared, the two cushions have more comparable crush forces. A length of the JEFF(B) bag crushes at a slightly lower force than the same length of the JEFF(A) bag because of differences in bag shape. However, the difference in energy-absorbing capability is compensated for by the greater depth (protrusion) of the JEFF(B) bag.

The load-deflection functions for the hard structure portion of the deflection range were calculated by using the member sizes and framing given on the latest design drawings available for the two craft. To be conservative, the strength of the hard structure was generally assumed slightly low. Calculations were made for the structure midway between frames where the most flexibility occurs. Also, only that structure in the vicinity of the machinery deck level was considered effective in energy absorption. This means that energy absorbed by frame deflections was ignored and some of the lighter members located higher on the craft were not included in the load-deflection definitions.

When the craft was modeled off-cushion, only the hard structure load deflection functions were defined. These load-deflection functions are presented in Figure 14 for the two craft at each of the initial impact locations. The load-deflection function for opposite corner impact includes the bumper response and is illustrated in Figure 15 for the two craft. The bumper load-deflection function was defined separately from the collision point load-deflection function since the loading was applied at a different point on the craft.

Figures 16 and 17 illustrate the load-deflection curves for the on-cushion JEFF craft at initial impact locations, and Figure 18 presents their on-cushion, opposite corner impact load functions.

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*Background for this work was reported informally by W.R. Conley in Enclosure (1) (The Use of Gas-Filled Bags for Impact Attenuation on the Arctic Surface Effect Vehicle) to NSRDC letter Serial 72-174-286 of 30 December 1972.

Figure 13 – Peak Crush Forces for the JEFF Cushions

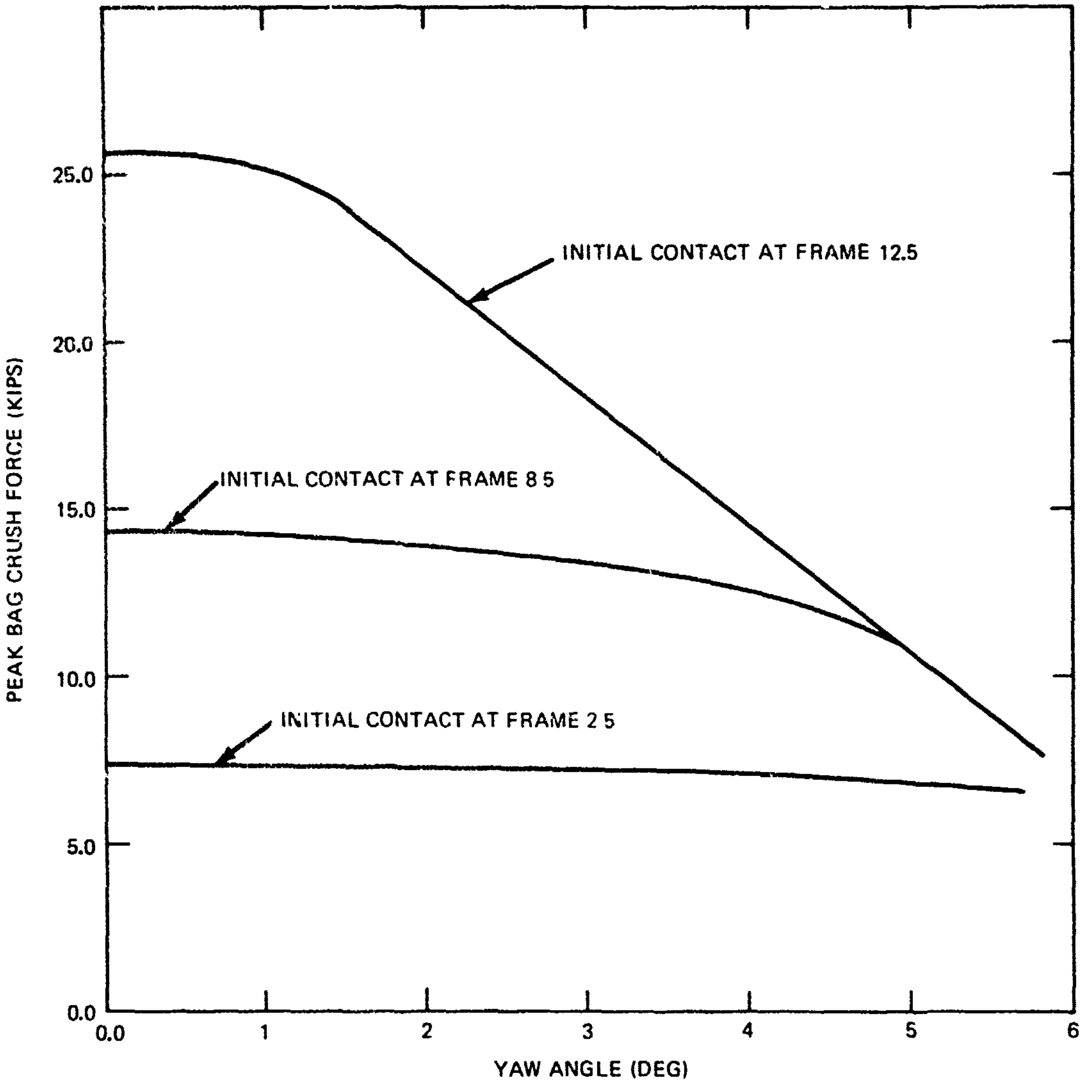


Figure 13a

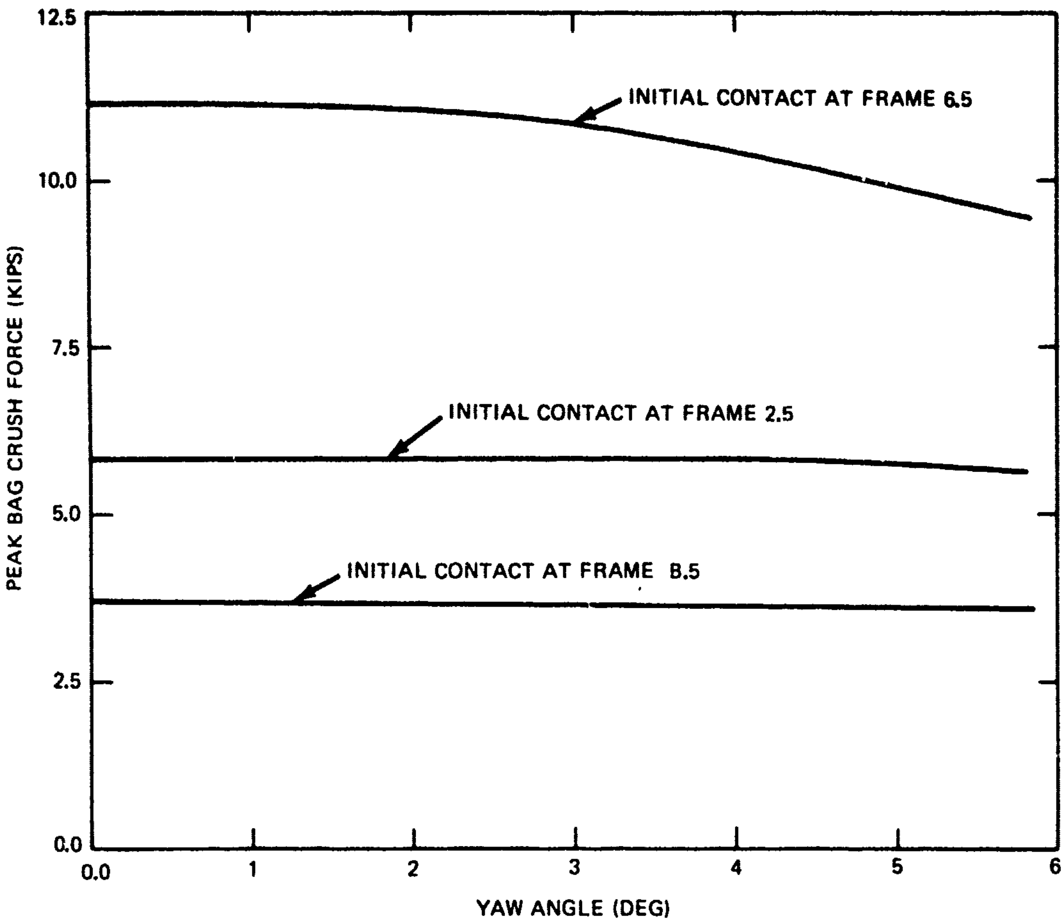

12.5
10.0
7.5
5.0
2.5
0.0
PEAK BAG CRUSH FORCE (KIPS)
0.0
1
2
3
4
5
6
YAW ANGLE (DEG)
INITIAL CONTACT AT FRAME 6.5
INITIAL CONTACT AT FRAME 2.5
INITIAL CONTACT AT FRAME B.5

Figure 13b

Figure 14 – Hard Structure Load-Deflection Function for the JEFF Craft

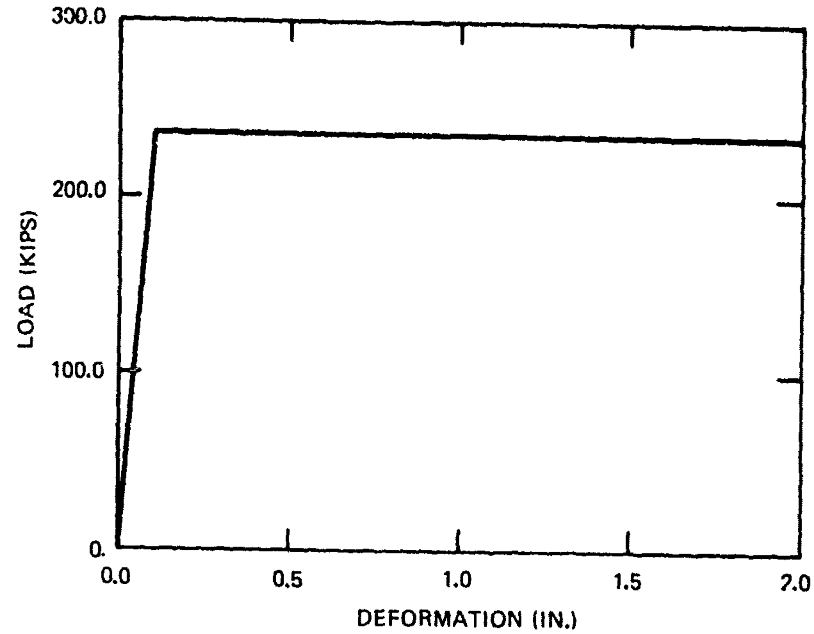


Figure 14a – For JEFF (A) at Frames 2.5 and 8.5

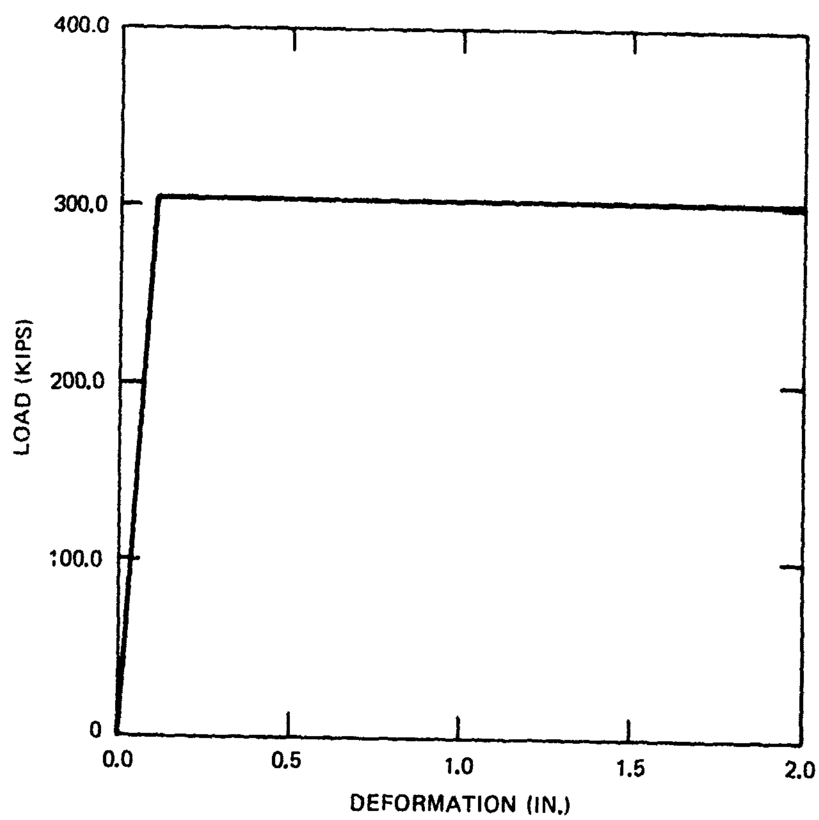


Figure 14b – For JEFF (A) at Frame 12.5

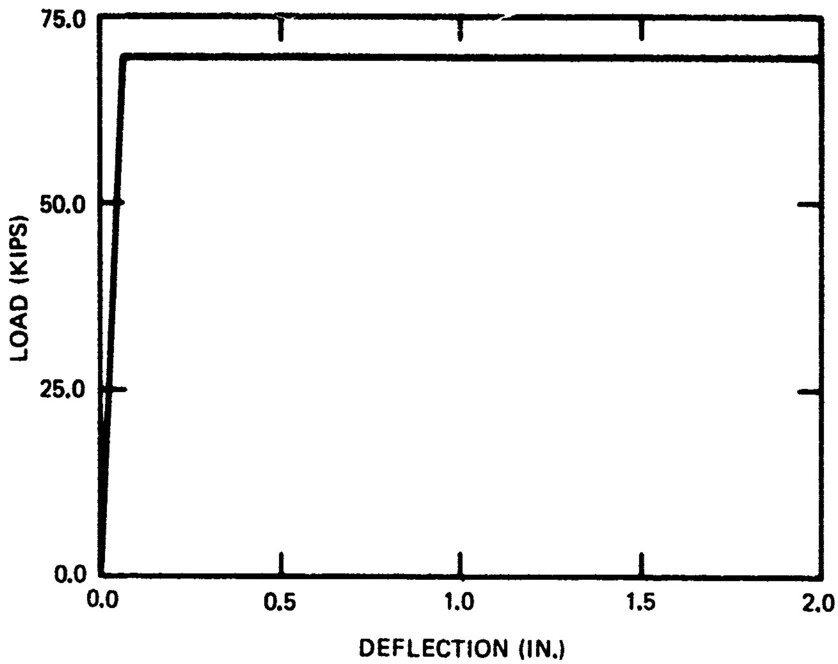
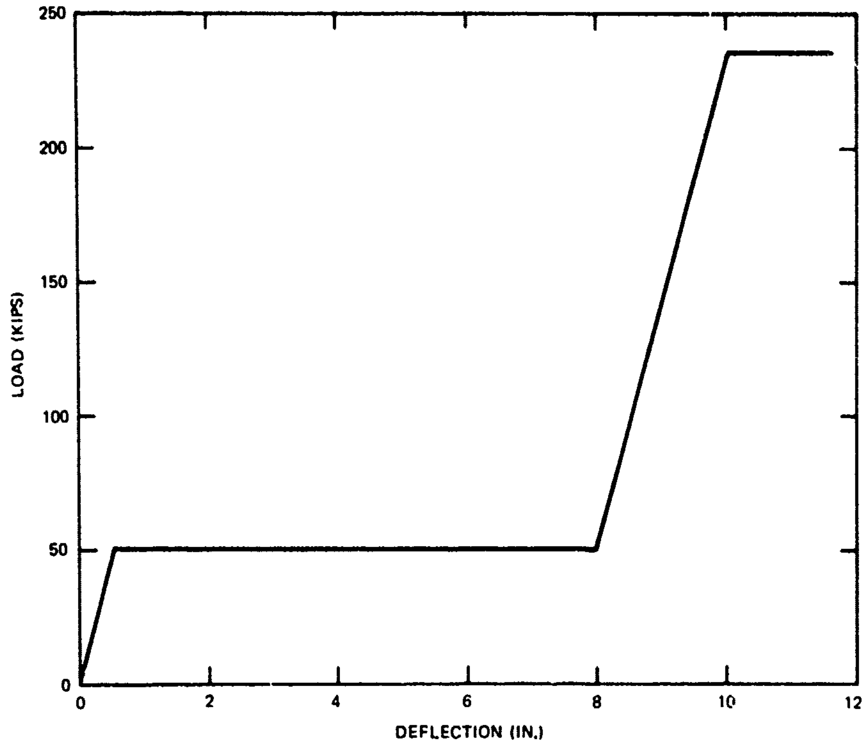


Figure 14c – For the JEFF (B)



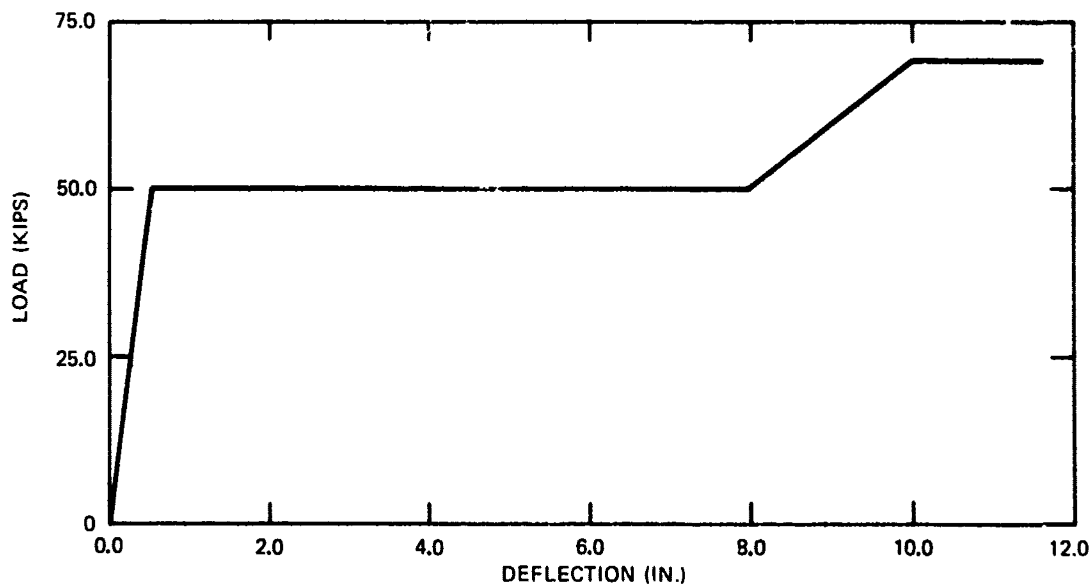


Figure 15 – Off-Cushion Opposite Corner Load-Deflection Function for the JEFF Craft

Figure 16 – On-Cushion Load-Deflection Function for JEFF(A) at Initial Impact Locations

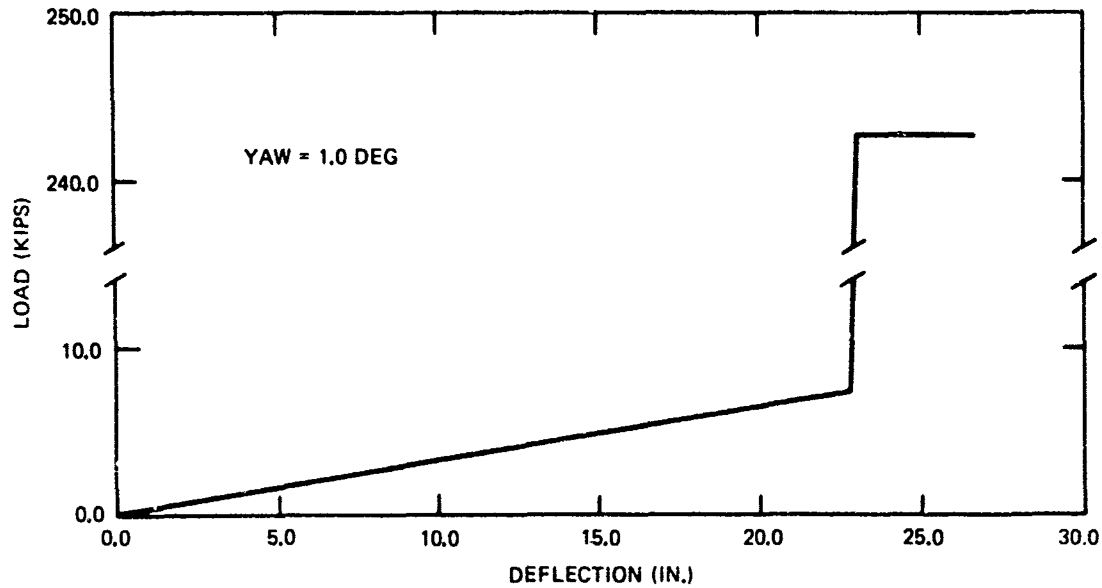


Figure 16a – Initial Impact at Frame 2.5

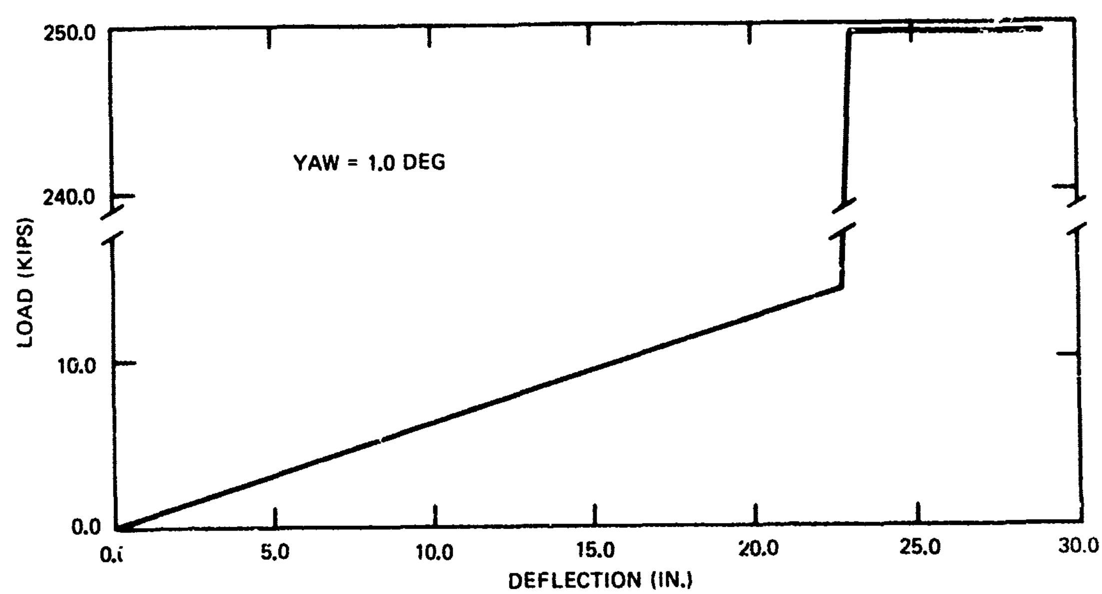


Figure 16b – Initial Impact at Frame 8.5

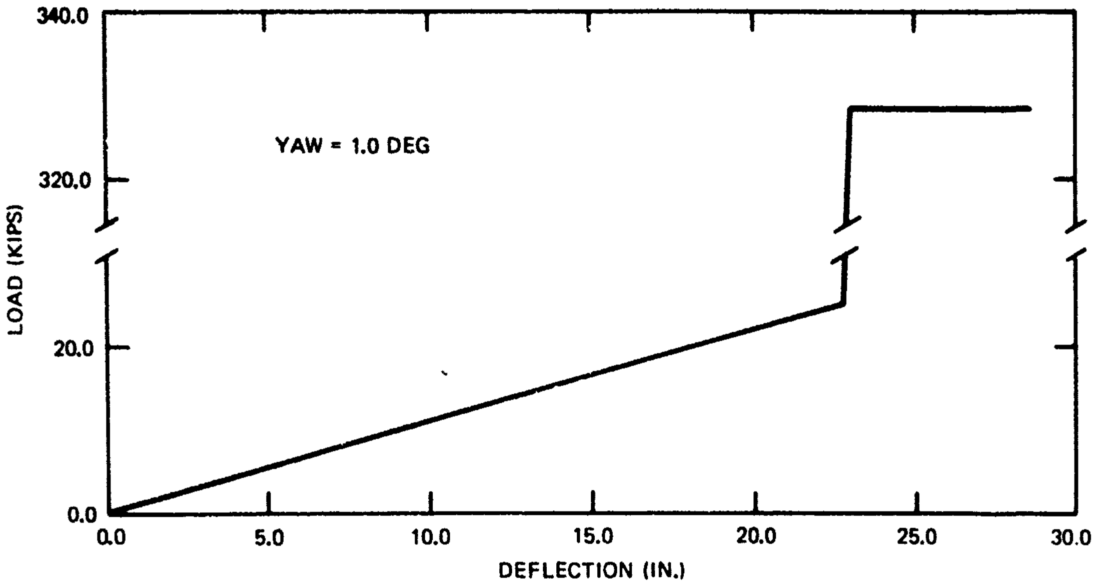


Figure 16c – Initial Impact at Frame 12.5

Figure 17 – On-Cushion Load-Deflection Function for JEFF(B) at Initial Impact Locations

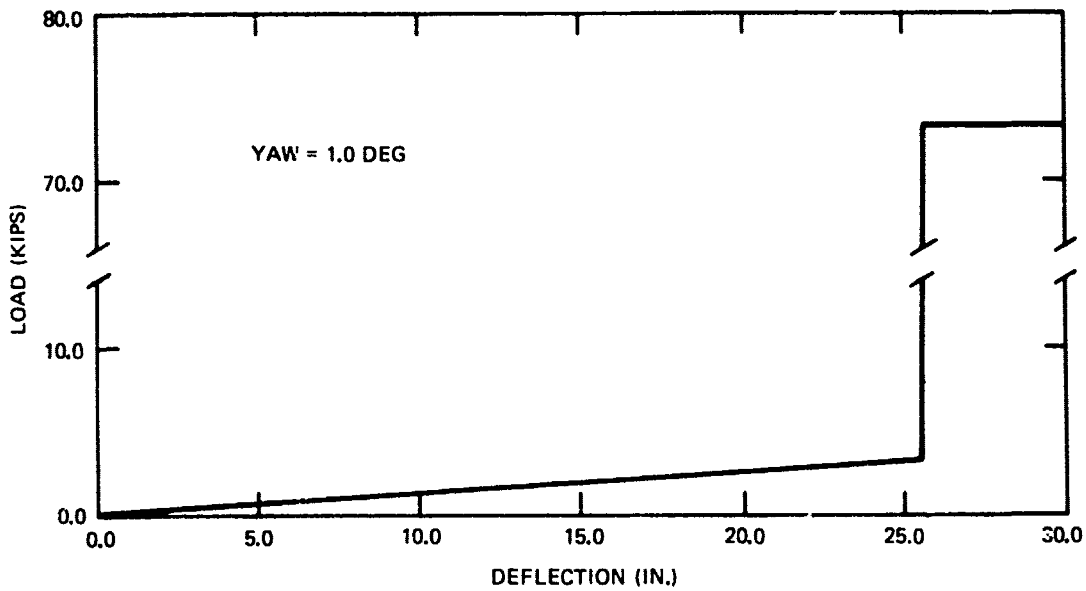


Figure 17a

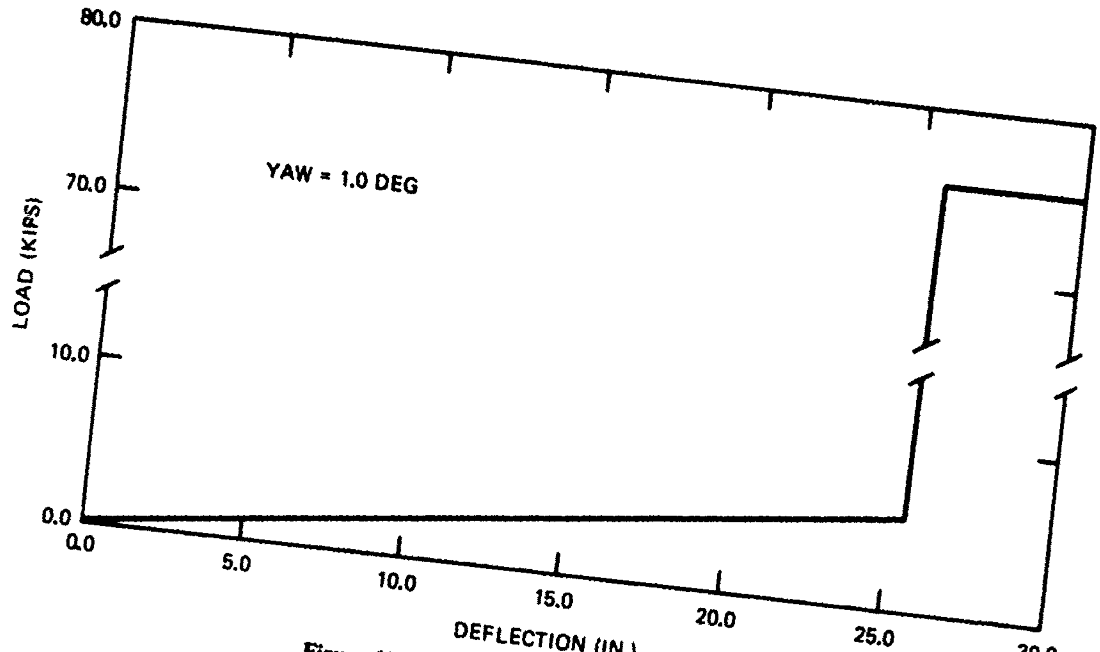


Figure 17b – Initial Impact at Frame 2.5

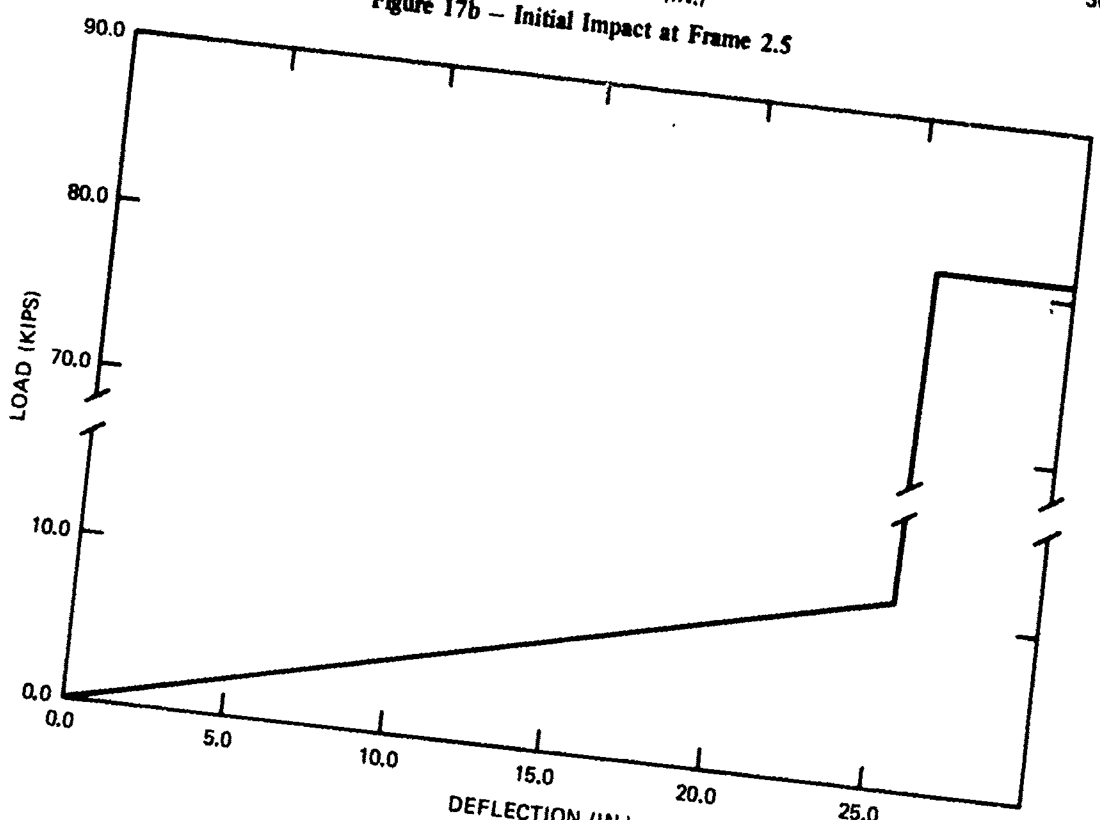


Figure 17c – Initial Impact at Frame 6.5

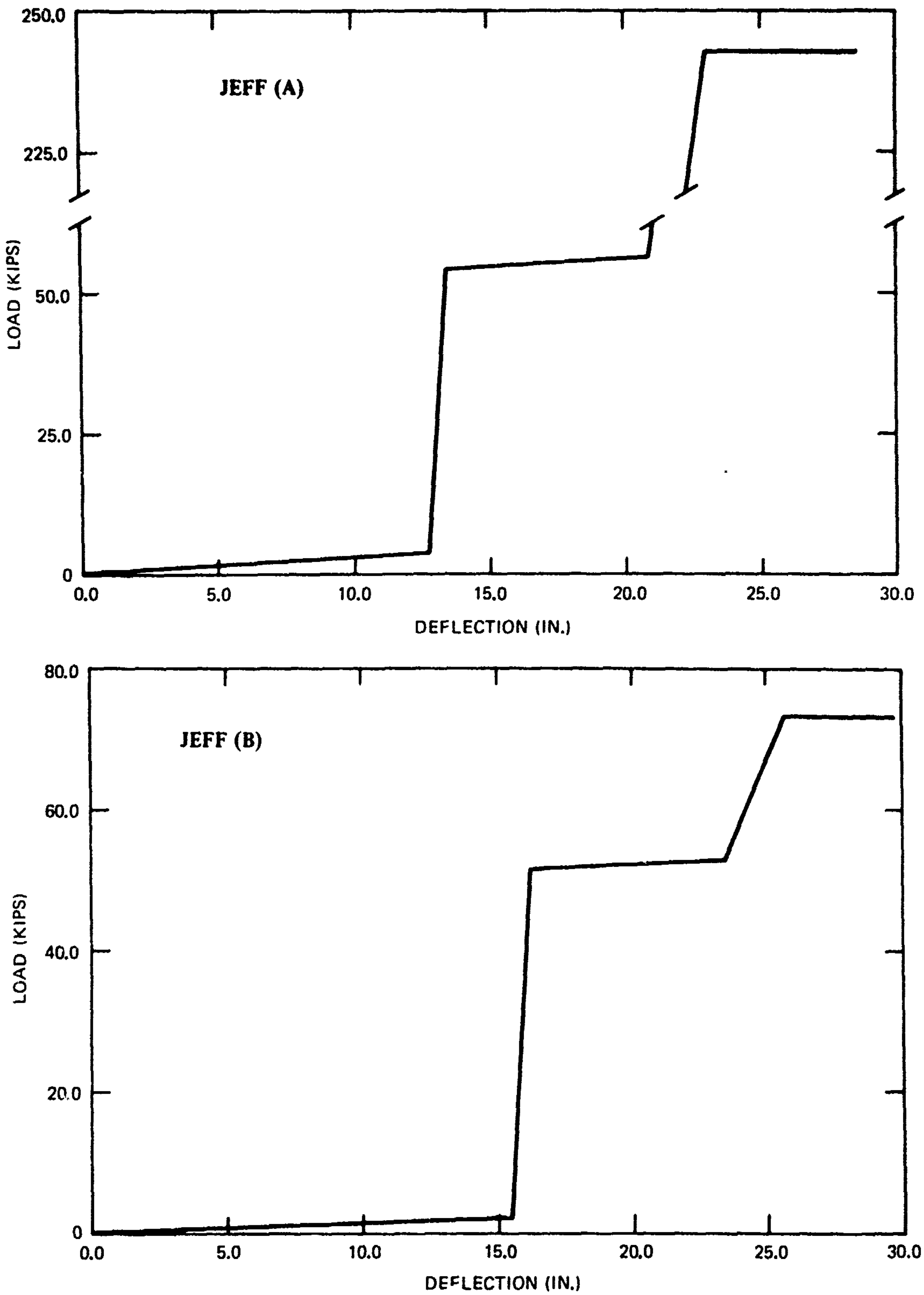


Figure 18 – On-Cushion, Opposite Corner Load-Deflection Function for the JEFF Craft

The location of critical equipment in the JEFF craft, principally on the machinery deck level, was used to define maximum allowable hard structure deflection for assessment of craft vulnerability in various impact conditions. Figure 19 presents the maximum allowable deflections as a function of location on the JEFF craft. Note that the maximum allowable deflection is zero in a few instances. This indicates that vital equipment is located on the outboard periphery of the structure. The propulsors, engines, and lift fans are located near the periphery on both craft. It may also be argued, of course, that the craft cannot function properly following damage to a large portion of the skirt system. Since the skirt is attached to the outboard periphery of the craft by a hinge line, this system is highly vulnerable under conditions of hard structure contact. A bumper or rubbing strip which protects the skirt hinge line is a necessity if hard structure contact cannot be avoided. Accordingly, hinge line protection is strongly recommended since off-cushion docking may be necessary and the present bumper design does not protect the entire craft length under all conditions.

ANALYSIS OF JEFF CRAFT RESPONSE

The analysis of the JEFF craft response to bow, side, and rolled impacts is divided into two segments, bow and side impact, and rolled impact. This division is a natural one in that bow and side collision forces and motions occur principally in the horizontal plane whereas rolled impact is assumed to occur principally in the vertical plane transverse to the JEFF. The analytical tools used to define impact damage and rigid body motions for both segments are now briefly described.

BOW AND SIDE IMPACT

A computer program was developed to calculate the rigid body motions and impact damage in bow and side impacts of the JEFF. Designated DOCK, this computer program is written in Fortran IV computer language and designed to run on the CDC 6700 computer operating under SCOPE 3.3 at NSRDC.

The program was written to solve the equations of motion for the JEFF craft when loaded with both impact loads and those resulting from impact motions. The principal response of the craft during docking impact is in the horizontal plane, and the program is written to handle only forces and motions in that plane (surge, sway, and yaw). The three degrees of freedom are considered to be uncoupled and the equations of motion are written as follows:

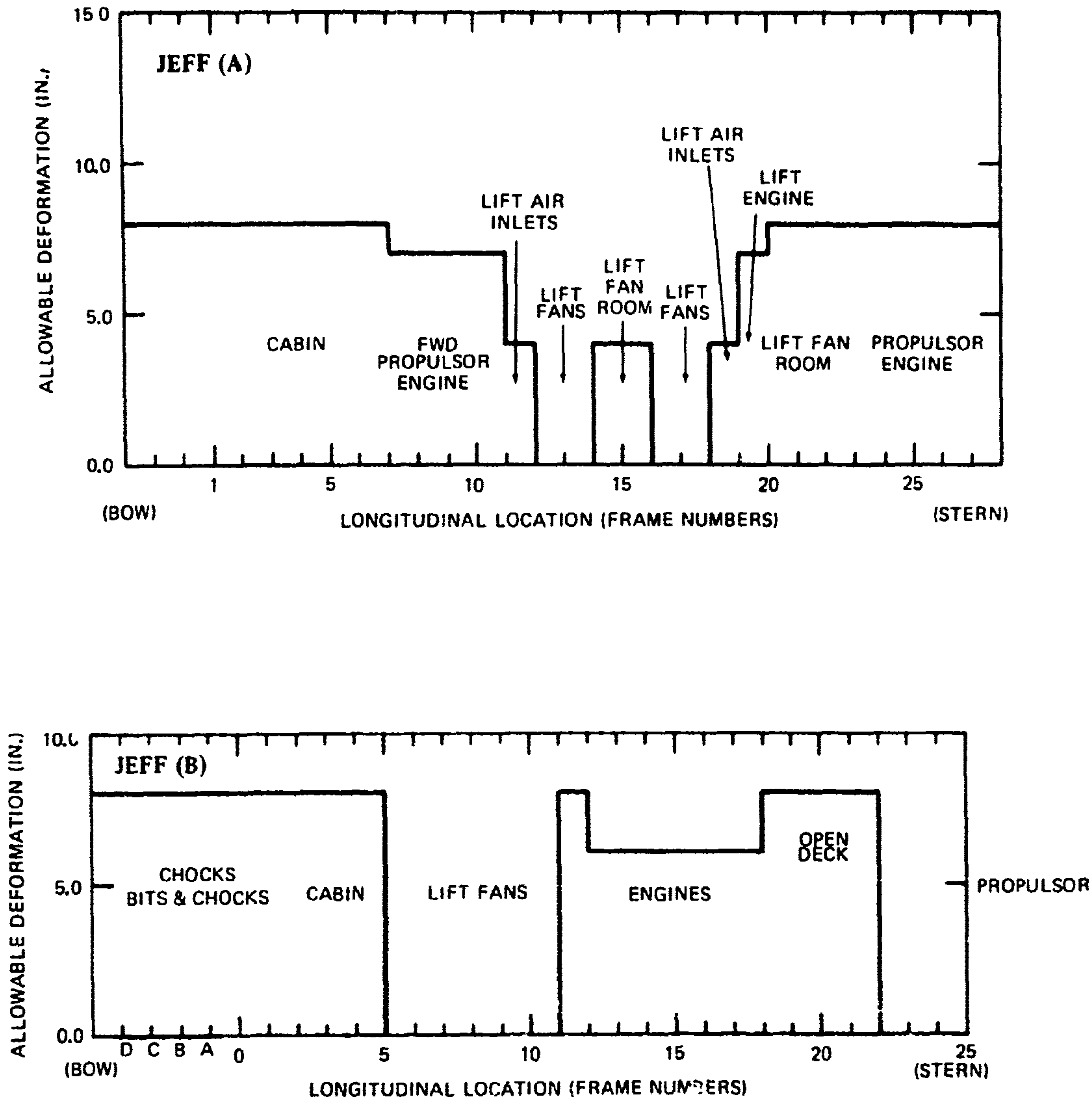


Figure 19 – Allowable Athwartship Hard Structure Deformation of the JEFF Craft

$$\text{"Sway" Motions:} \quad F_x = M \frac{d^2 X}{dt^2}$$

$$\text{"Surge" Motions:} \quad F_y = M \frac{d^2 Y}{dt^2}$$

$$\text{"Yaw" Motions:} \quad M_\theta = I \frac{d^2 \theta}{dt^2}$$

where F_x = summation of all force components on the craft in the "sway" direction (in pounds)

M = craft translational mass (in pound-second^2/inch)

X = "Sway" motion (in inches)

t = time (in seconds)

F_y = summation of all force components on the craft in the "surge" direction (in pounds)

Y = "Surge" motion (in inches)

M_θ = summation of the moments of all forces about the craft center of gravity (in inch-pounds)

I = craft rotational inertia (in pound-second^2-inch)

θ = yaw motion (in radians)

Quotation marks are used here with the terms "sway" and "surge" because strictly speaking, they are not the sway and surge motions of the JEFF. It is convenient to calculate the rigid body response of the JEFF with respect to a "static" coordinate system. Although both the JEFF and the LPD/LSD are underway during a docking, the motions critical to docking are relative motions. For this reason, it is possible to consider the well deck as stationary and the JEFF as moving at the relative motion between the two. The "static" coordinate system is thus taken to be oriented with the LPD/LSD. This assumption implies that the LPD/LSD remains at constant velocity during the collision process. The y-direction ("surge" direction) is parallel with the centerline of the well deck and the x-direction ("sway" direction) is oriented transverse to the well deck centerline. Note that these directions for the "static" coordinate system are not always aligned with the directions of the JEFF surge and sway.

The "static" or ground coordinate system is convenient for calculating rigid body motions, but a craft coordinate system is more convenient for calculating forces and damage on the JEFF. This "craft" coordinate system is oriented with the y-direction parallel to the JEFF centerline and with the x-direction perpendicular to the craft centerline. Therefore, as the

JEFF moves with time, so also does the craft coordinate system. The craft coordinate system views motions as the JEFF helmsman will view them (from the craft). In contrast, the ground coordinate system views motions as seen from the LPD/LSD. Output from program DOCK is in terms of both coordinate systems.

The sign convention is as follows: position y indicates forward motion, position x motion to starboard, and position rotation clockwise motion as viewed from above the craft.

Table 5 presents solutions for the equations of motion at the craft CG in the ground coordinate system. Rigid body response at a location distant from the craft CG is simply the rigid body motion of the CG plus any motion from rigid body rotation. Equations (2) and (3) define translational velocity and displacement motion at a distance r from the CG. This motion is in a direction perpendicular to the position vector locating the point of interest from the CG. This motion must be resolved to its components in the ground coordinate system principal directions before summation with the rigid body translation motions.

$$V_r = r\omega \tag{2}$$

$$d(Z_r) = r(d\theta) \tag{3}$$

where V_r = translational velocity of the remote point

ω = rigid body rotational velocity about the CG

$d(Z_r)$ = change in the rigid body translational displacement at the remote point due to rotation

$d\theta$ = change in the rigid body rotation of the CG

r = distance from the CG to the remote point of interest

The dimensions of the craft and the well deck are specified and so are the initial velocities and orientations of the craft at impact. Contact with the well deck entrance corner is initiated at a specified location on the periphery of the craft. As the motion of the craft carries the collision point along the craft and into it, the location of the impact point is shifted. The distance the collision point travels into the craft is actually deflection of the craft at the collision point. The solution is a numerical integration and a time-marching process, that is, the solution is computed at very short time increments and the motions at the end of a given time step are used to define parameters for the next increment. The impact load is defined from the deflection calculated in the previous time increment and the load-deflection curve specified as a part of the impact data.

As the collision forces and craft momentum cause the craft to move as a rigid body and locally deform at the impact location, the collision geometry changes. Because of the rather

TABLE 5 – EQUATIONS FOR RIGID BODY MOTION

	X-Direction	Y-Direction	θ-Direction
Acceleration at CG	F_x/M	F_y/M	$\alpha = M_\theta/I$
Velocity at CG	$V_x = F_x\ \Delta t/M + V_{0x}$	$V_y = F_x\ \Delta t/M + V_{0y}$	$\omega = \alpha\Delta t + \omega_0$
Displacement at CG	$X = F_x\ \Delta t^2/2M + V_{0x}\ \Delta t + X_0$	$Y = F_y\ \Delta t^2/2M + V_{0y}\ \Delta t + Y_0$	$d\theta = \alpha\Delta t^2/2 + \omega_0\ \Delta t$ $\theta = d\theta + \theta_0$
Initial Conditions	$V_{0x} = V_0 \sin\phi$	$V_{0y} = V_0 \cos\phi$	$\omega_0 = 0$

limited clearances in the well deck, it is likely, for example, for the bow corner of the on-cushion craft on the side of the craft opposite from the initial impact location to collide with the opposite sidewall of the well deck. When this occurs, the opposite corner is loaded with normal crush forces and sliding friction forces much like the collision side impact point. The crush forces are defined incrementally from the deflection at the end of the previous time step and from a load-deflection curve specified for the opposite corner.

A load-deflection function is also specified for the energy-absorbing bumper when the impact is a side collision. For bow collisions, the bumper characteristics can be described in the load-deflection function of the collision point since, for all practical purposes, if a bumper is involved in a bow collision, the forces resulting from bumper deformation are coincident with the impact point crush forces. When the JEFF rotates sufficiently so that its bow corner opposite to the collision side will impact the well deck sidewall, the bumper forces on the opposite corner are equivalent to the cushion and hard structure crush forces. But when the collision side bumper is impacted, the location of the bumper forces is always at the forward corner where the bumper is located; in contrast, the impact point (well deck corner to side of the JEFF craft) is constantly moving aft on the craft as the JEFF moves into the well deck. These forces are illustrated in Figure 20.

Bookkeeping is a major role of the program in that it keeps track of craft location and orientation relative to the well deck corner and sidewalls. This system defines when bumper contact occurs, when opposite corner contact occurs, when the collision is ended, and when the various forces associated with the impact are applied.

The collision is ended for a single impact when the impact point (the point on the craft where the well deck corner contacts the craft) starts moving away from the well deck corner. This action breaks contact with the well deck corner, the impact loads drop to zero, and the single impact collision is ended. This does not necessarily mean that the JEFF velocity toward that well deck corner is zero or negative, however. The impact point is located at some distance from the craft CG and it is possible for rigid body rotation to counter the rigid body translation of the impact point and cause the impact point to move away from the well deck corner while the CG continues to move toward the corner.

The multiple impact option available in the program allows for craft motion after the impact point breaks contact with the well deck corner. The craft is allowed to move in free flight until another point on the craft contacts the well deck and a secondary collision begins.

Both the single and multiple impact analyses end when the craft is completely within the well deck in the case of side collisions or when the craft is not aligned to impact the stern of the LPD/LSD in the case of bow collisions.

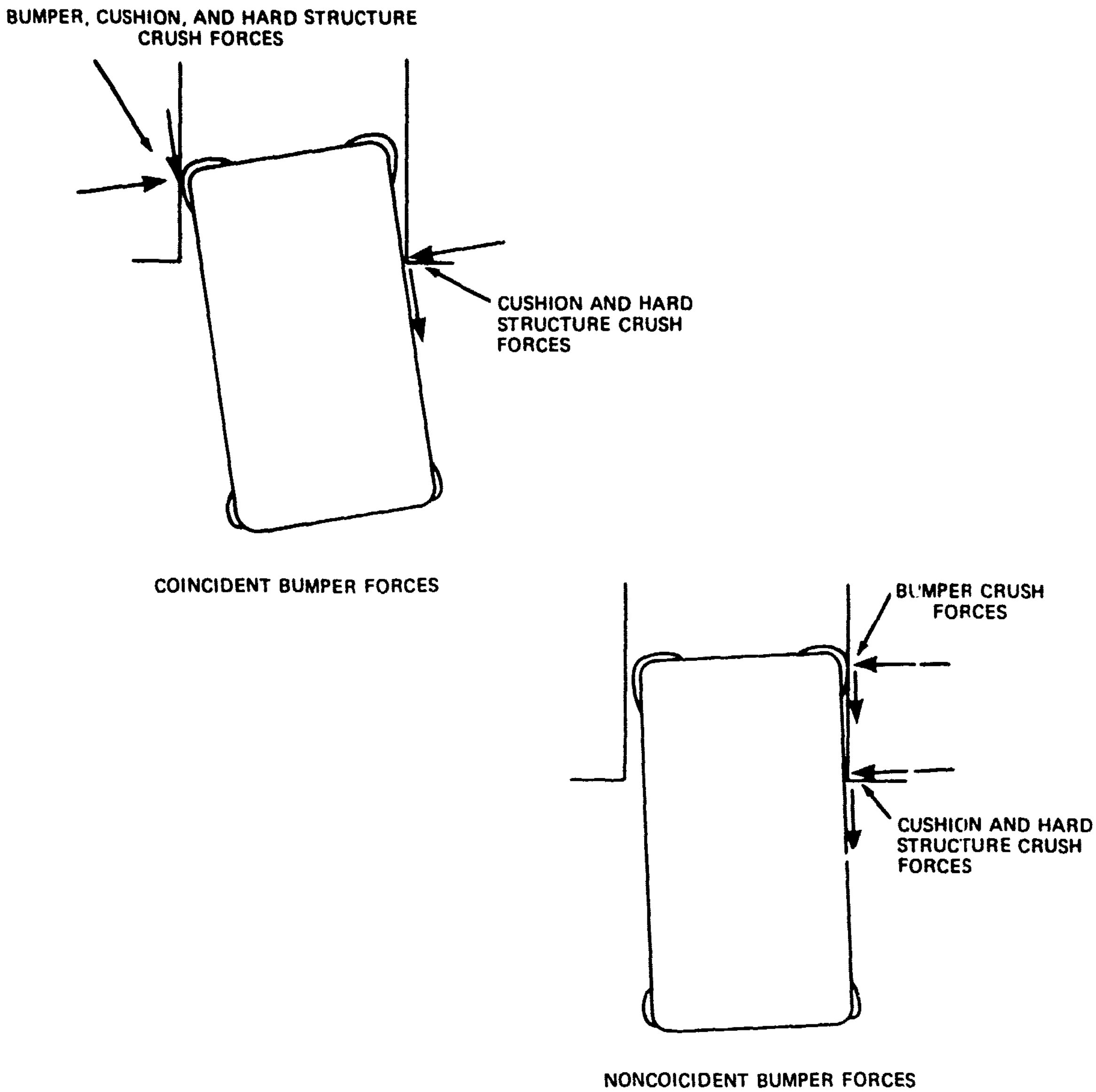


Figure 20 – Location of Coincident and Noncoincident Bumper Forces

The program has the capability to define the impact loading parallel with the impacting surface in a number of different ways. Two of the options involve a sliding friction force; this force is defined as a specified friction coefficient times the crush force. One of the two sliding friction options allows a modification of the crush load for proximity to transverse frames. Another option defines surface loading by a load-deflection function; here, the surface force is defined from the function and the calculated motion along the surface. Finally a "no sliding" option is available whereby a surface force is calculated such that no motion of the impact point occurs. This option is intended to analyze impacts wherein damage causes the craft to "hang" on the well deck corner. This condition can only be approximated in DOCK since a set of forces is assumed to be constant for a time increment.

When the impact point has a surface velocity at the beginning of the time increment and if the displacement at the end of the increment is to be zero, then the point must be allowed to move off the well deck corner during the time increment in order to arrive back at the corner by the end of the time increment. This excursion is a function of the time increment selected but generally it is insignificant. The force required to approximate the "no slide" condition is calculated from Equation (4) for a bow collision and from Equation (5) for a side collision. Figure 21 defines some of the variables used in Equations (4) and (5).

$$F_T = \frac{V_{0y} \sin\theta - V_{0x} \cos\theta - B\left(\omega_0 + \dfrac{\Delta t\, F_c\, E}{I_c}\right)}{\dfrac{I_c + M\, B^2\, \Delta t}{M\, I_c}} \tag{4}$$

$$F_T = \frac{E\left(\omega_0 - \Delta t\, \dfrac{F_c\, B}{I_c}\right) - V_{0x} \sin\theta - V_{0y} \cos\theta}{\dfrac{I_c + M\, E^2 \Delta t}{M\, I_c}} \tag{5}$$

where F_T = surface force in pounds

V_{0y} = velocity at the beginning of the time increment of the impact point in the "surge" direction in inches per second

V_{0x} = velocity at the beginning of the time increment of the impact point in the "sway" direction in inches per second

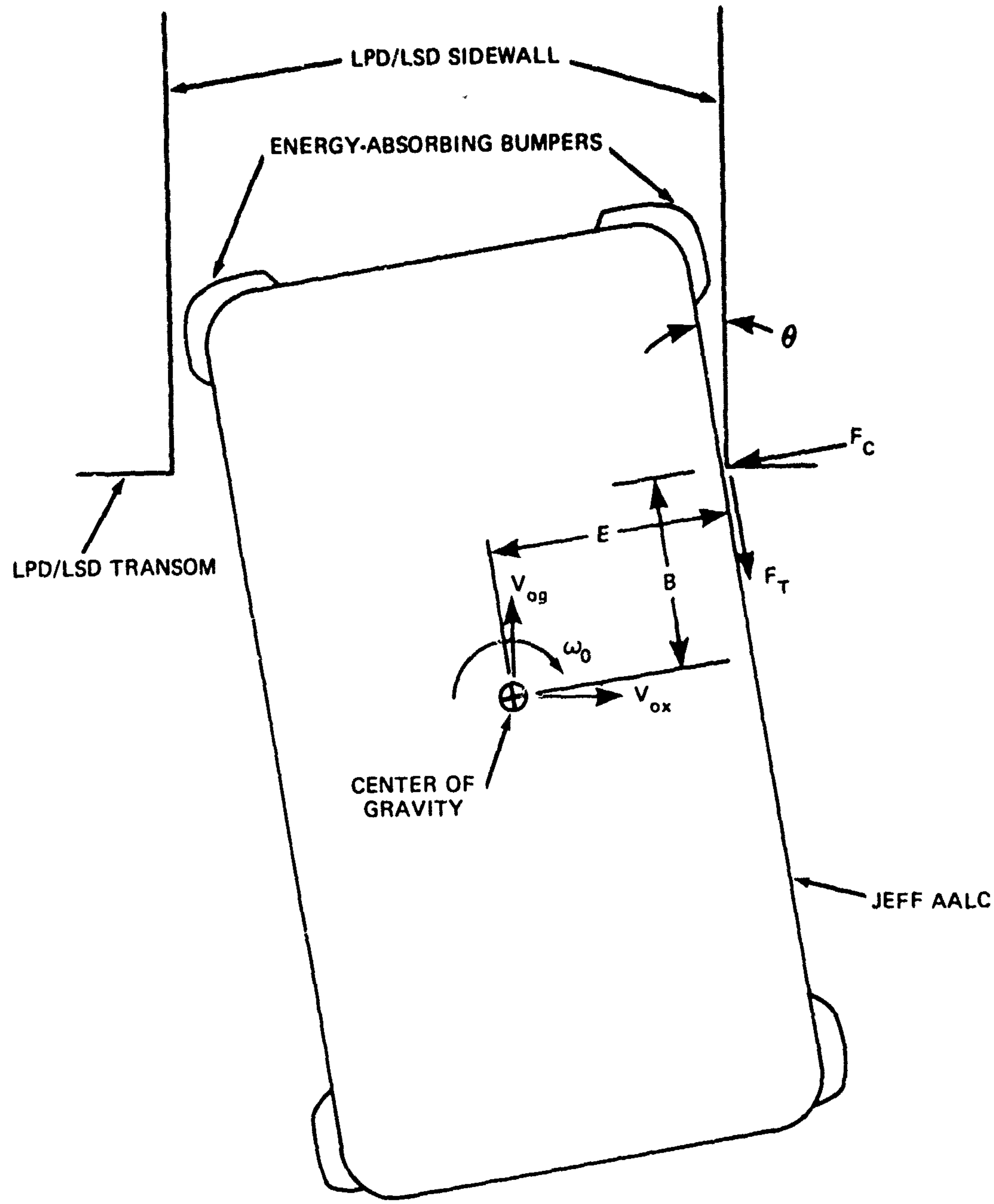


Figure 21 – Definition of Craft Orientation and Relative Motion Parameters

ω_0 = rotational velocity at the beginning of the time increment in radians per second

Δt = time increment in seconds

M = translational mass in pounds-second^2 per inch

I_c = rotational inertia in pounds-seconds^2 inch

θ = yaw angle at the beginning of the time increment in radians

F_c = crush force in pounds

B = distance from the craft CG to the impact point in the surge direction

E = distance from the craft CG to the impact point in the sway direction

These equations were derived by double integrating the equations of motion in the craft coordinate system over the time increment and solving for the surface force F_T when the surface deflection of the impact point at the end of the time increment is equal to zero.

The AID craft-handling system for the LPD/LSD can be modeled in another option of DOCK. Figure 10 illustrates locations of the system cables. The program approximates the cable locations as parallel to and transverse to the centerline of the LPD/LSD. All cables are oriented at a vertical angle which is modeled for cable stress calculations, but no vertical force components from the cable are defined on the craft model since the simulation is limited to the horizontal plane. Each of the cables is specified with a preload, an elastic strength, a plastic strength, and a limit elongation. When the craft moves so that a cable is in tension, the load from that cable is defined from its elongation. When and if the elongation exceeds the cable limit, the cable "breaks" and is no longer available for restraint in the analysis. The actual AID system is designed to limit the loading in the longitudinal cables by control of the carriages (to which the cables are attached) on the tow-in rails. This limit loading is also included in the AID system model. Since the AID system is designed to move into the well deck with the craft, the longitudinal cable forces act in pairs as a force couple on the bow of the JEFF to resist rotational impact motions. Of course, the cables also tend to keep the craft moving into the well deck, and this can lead to more severe impacts. Because of the vertical angle of the tow-in cables and their limited strength (elongation), the AID craft-handling system is not expected to be a significant factor either in inducing or in reducing side collision damage. Since the tow-in system must be attached to the JEFF chocks as the craft enters the well deck, the system is not functional until the craft is at least partially docked. The system, then, is not a factor in bow collisions.

Program DOCK has been set up for consecutive running of any number of docking impact analyses. The detailed impact data definition and user's manual are presented in Appendix A, and a listing of the program is given in Appendix B.

ROLLED IMPACT

Computer program DOCK is limited to docking collision analyses in the horizontal plane. All forces and motions are restricted to that plane. When the craft impacts the well deck corner in an initially rolled orientation relative to the LPD/LSD, motions out of the horizontal plane are expected. In order to evaluate this form of impact and determine its severity, a separate, two degree-of-freedom analysis is made.

Figure 22 illustrates rolled impact. The impact model defined is limited to lateral translation of the craft (sway) and roll. The impact force is applied at the collision point, as shown in Figure 22, and the CG is assumed to be located at a distance H from the top of the frame where the impact force is applied. It is further assumed that the rolled-impact force is the only force on the craft significant to the rolled-impact study. This, of course, precludes propulsion and control forces, the weight of the craft, buoyancy, and hydrodynamic forces. The impact force is assumed to be constant over the impact time.

The translational and rotational accelerations of the craft CG are defined as follows:

Translational Acceleration: $a = P/M$

Roll Acceleration: $\alpha = PH/I$

where M and I are the translational and rotational inertias in the roll plane. V_{cg}, the translational velocity of the CG, is obtained by integrating the defined acceleration to time t:

$$V_{cg} = V_0 + at \tag{6}$$

where V_0 is the initial translational velocity. Similarly, in the rotational direction, the roll velocity ω is defined as:

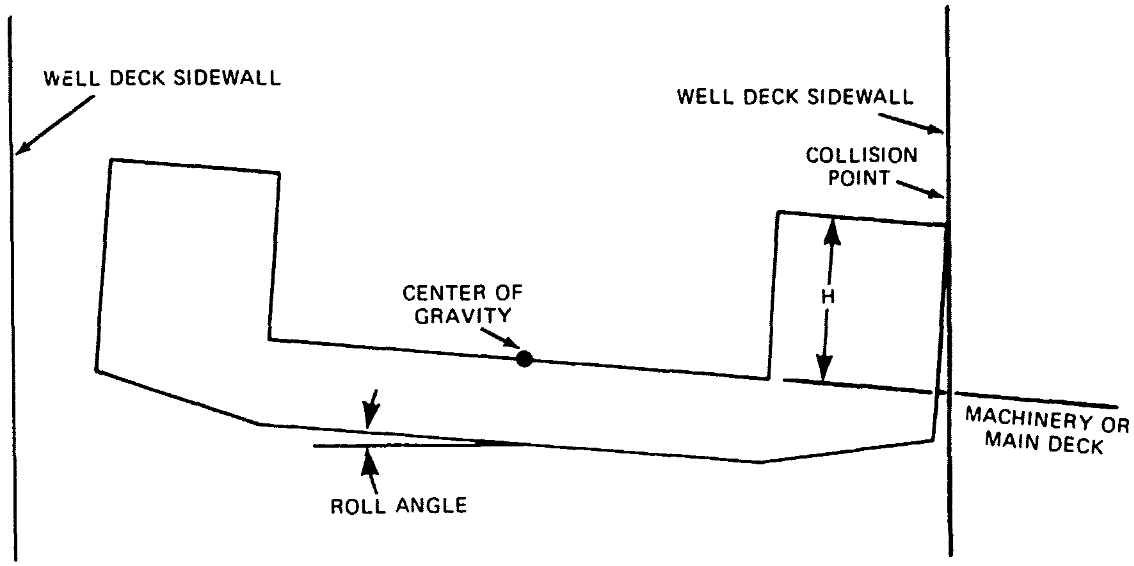
$$\omega = \omega_0 + \alpha t \tag{7}$$

where ω_0 is the initial roll velocity of the craft. V_{tf}, the translational velocity at the top of the frame, is defined in Equation (8).

$$V_{tf} = V_{cg} + \omega H \tag{8}$$

Equations (6) and (7) may be integrated to define the rigid body displacements of the CG.

$$X_{cg} = X_0 + V_0\ t + 1/2\ at^2 \tag{9}$$



TRANSVERSE CROSS SECTION OF THE JEFF
(FLEXIBLE CUSHION SYSTEM NOT SHOWN)
CRAFT OFF-CUSHION

Figure 22 – Rolled Impact of the JEFF Craft

$$\theta = \theta_0 + \omega_0 t + 1/2 \alpha t^2 \tag{10}$$

where X_{cg} = displacement of the CG at time t

θ = rotation of the CG at time t

X_0 = initial displacement (usually assumed to be zero)

θ_0 = initial roll angle

The displacement at the impact point X_{tf} is calculated from the displacements at the CG:

$$X_{tf} = X_{cg} + (d\theta) H = X_{cg} + \theta H - \theta_0 H \tag{11}$$

Combining Equations (9), (10), and (11) and assuming X_0 as equal to zero, this becomes

$$X_{tf} = V_0 t + 1/2 at^2 + \theta H - \theta_0 H \tag{12}$$

Thus far the rigid body response of the craft to time t has been defined. Since X_{tf} is the deflection of the top of the frame or the point of impact, the damage is also defined as a function of time.

The collision ends for the rolled-impact condition in one of two ways: (1) when the velocity at the top of the frame is brought to zero ($V_{tf} = 0$) or (2) when the JEFF is sufficiently rotated to cause its main deck to be impacted. The latter condition changes the impact from the rolled case to impact in the horizontal plane; this is analyzed separately by computer program DOCK.

In the first case, where the velocity at the top of the frame is brought to zero, the time to the end of the collision is defined by setting V_{tf} equal to zero and solving for time t in Equation (8). This results in a definition of the time for Case 1 (t_1) as:

$$t_1 = - \frac{[V_0 + \omega_0 H]}{[P/M + P H^2/I]} \tag{13}$$

In the second case, where the collision ends when the main deck (assumed to be located at the level of the CG) contacts the well deck, the time at the "end" of the collision is defined by setting the displacement of the CG equal to the initial offset of the main deck from the well deck and solving for time t in Equation (9). The initial offset of the main deck from the well deck is defined as:

$$X_{MDO} = \theta_0 H$$

The time at which the collision ends in Case 2, (t_2), then, is defined as:

$$t_2 = \frac{M}{P} \left[- V_0 \pm (V_0^2 + 2 P \theta_0 H/M)^{1/2} \right] \tag{14}$$

Equation (14) is the solution of a quadratic equation. The smallest, real, positive value for t_2 is selected and compared with t_1. The smaller value is then regarded as the time at which the collision "ends." Use of this time in Equation (11) defines the rolled-impact damage.

This theory was used to parametrically investigate rolled-impact damage and the results are included in the report.

RESULTS OF THE DOCKING VULNERABILITY ANALYSES

It is impossible to give here the entire mass of data which resulted from the study. Accordingly, the presentation is limited to the general trends of the data and the important conclusions reached.

BOW IMPACT

Figure 23 presents the maximum crush distance or maximum damage on a bow collision for the JEFF(A) loaded and unloaded in both operational modes as a function of the angle between the velocity vector and the well deck centerline at various yaw angles. It can readily be seen that the bow collision response does not depend significantly either on velocity attack angle or on yaw angle for the range of those parameters considered. On-cushion damage was fairly constant at about 7.5 in. of deflection for the loaded JEFF(A) and about 4.5 in. of deflection for the unloaded JEFF(A).

There is a slight variation of damage with bow impact geometry for off-cushion response. This has been exaggerated by the vertical scale of the graph to illustrate the variation. The same type of variation also occurred in on-cushion bow collision response.

Deformations of up to 11.5 and 8.5 in. are predicted for bow impacts of the off-cushion JEFF(A), in the loaded and unloaded conditions, respectively. Since the hard structure is

Figure 23 – Bow Impact Damage Predicted for the JEFF(A)

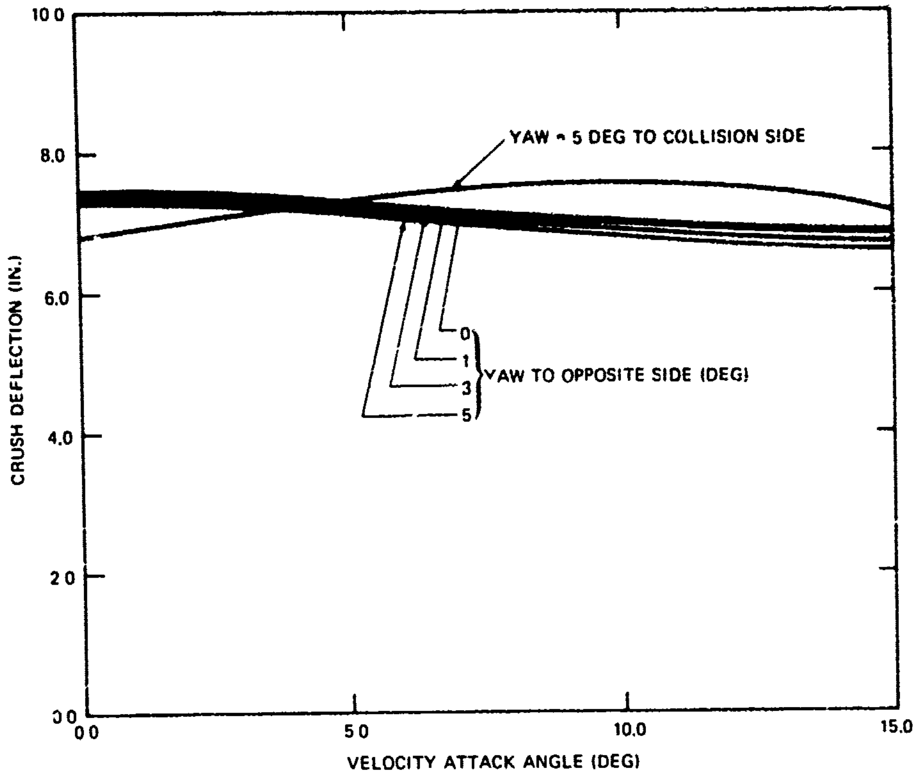


Figure 23a – On-Cushion, Loaded

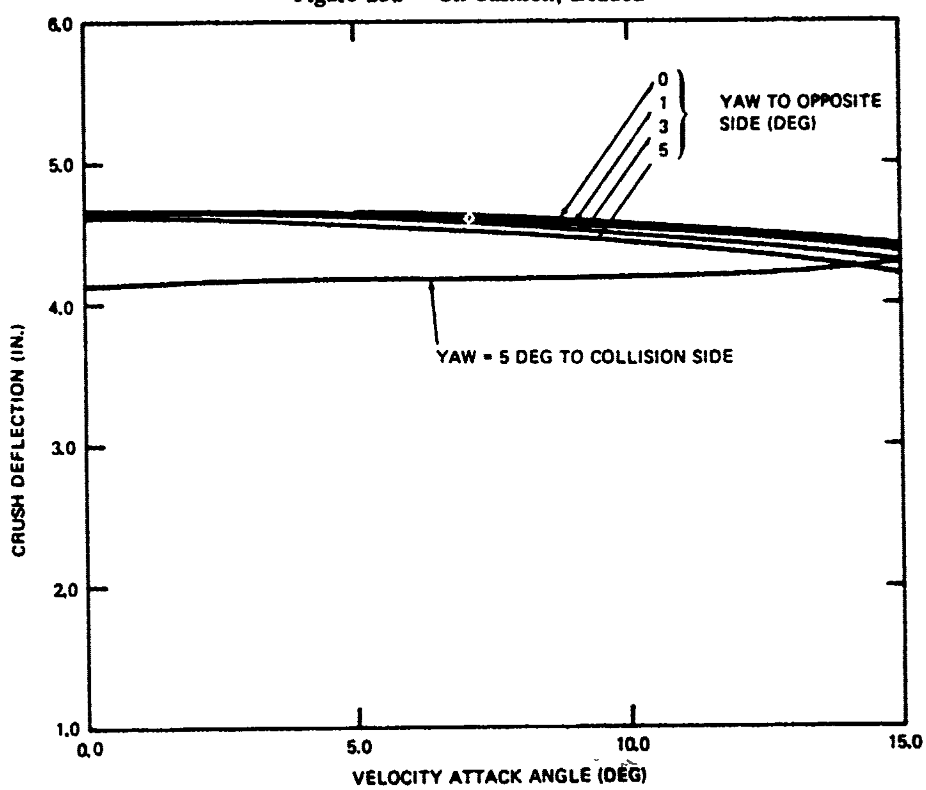


Figure 23b – On-Cushion, Unloaded

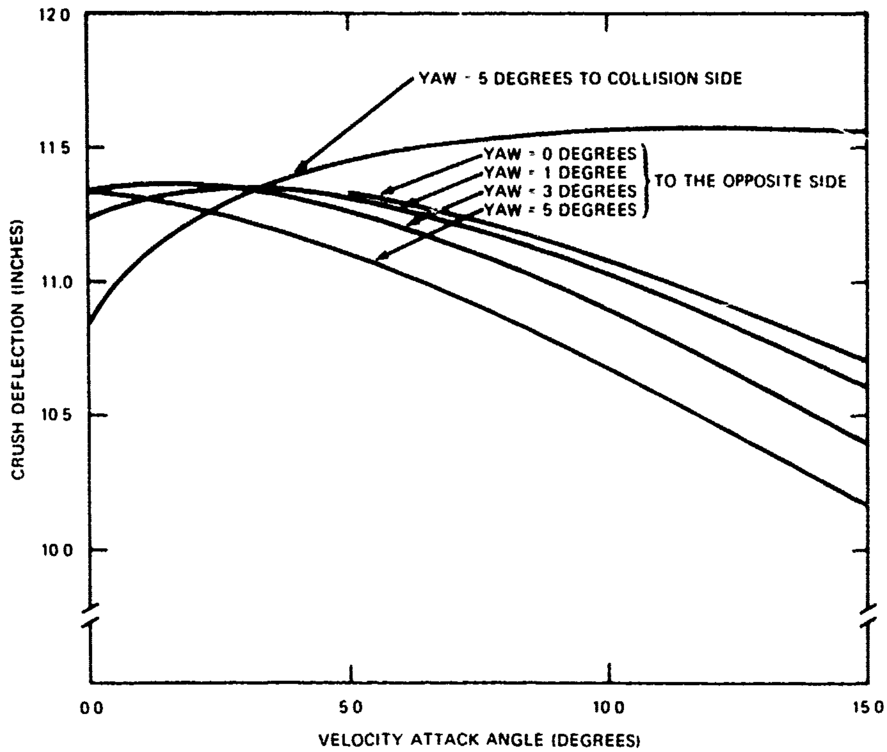


Figure 23c – Off-Cushion, Loaded

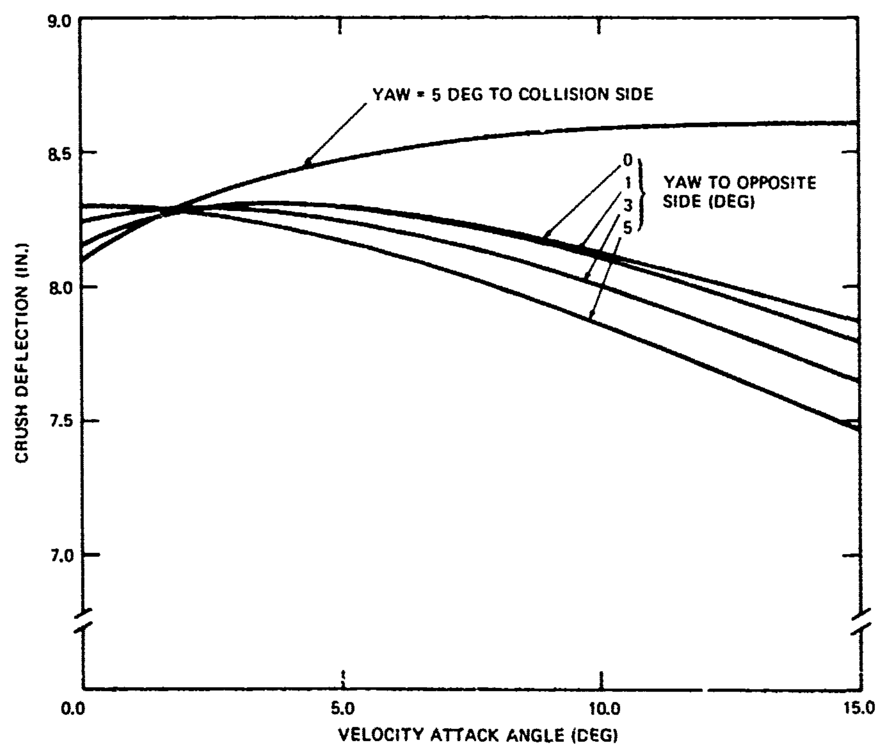


Figure 23d – Off-Cushion, Unloaded

assumed to start deforming after the energy-absorbing bumper is fully crushed, this implies 2 to 3 in. of hard structure damage. It is unlikely that such damage in this region will disable the craft. Some problems with structural integrity in the vicinity of the chocks may result, and the bow ramp mechanism may experience some hinge mechanism alignment problems. A single bow impact of the off-cushion JEFF(A) will probably not disable the craft, but sufficient plastic deformation can occur in the bow structure (including probable elimination of the bumper) so that subsequent impacts in the same region are likely to cause serious damage.

Figure 24 shows a typical time history of the crush deflection for a bow impact on the JEFF(A). The bow collision is characterized by a nearly linear deflection with time until the collision is almost complete and then a marked departure as the hard structure of the craft begins to deform. The bow collision is very rapid, lasting only 0.5 to 0.75 sec for off-cushion impacts and only 0.3 to 0.5 sec for on-cushion impacts. Rigid body decelerations on the order of 0.3 g are predicted for the worst-case bow impacts. This occurs in the on-cushion unloaded craft and is not severe enough to cause damage to onboard equipment.

Figure 25 presents the crush deflections for bow impact orientations of the on- and off-cushion JEFF(B) loaded and unloaded. On-cushion bow damage is expected to be fairly constant at about 7.0 and 4.0 in. of deflection for the JEFF(B) loaded and unloaded, respectively. This damage is within the dimensions of the energy-absorbing bumper and therefore no hard structure damage should occur for these cases. The on-cushion JEFF(B) bow impact damage was about 90 percent of the JEFF(A) bow damage, principally because of the difference in craft mass.

Bow-impact damage for the off-cushion JEFF(B) is predicted to be fairly constant with impact orientation and equal to abcut 9.5 and 7.5 in. for the loaded and unloaded craft, respectively. The off-cushion JEFF(B) bow impact damage is predicted to be about 85 percent of the JEFF(A) bow damage, again primarily because of the difference in craft mass. Consequences of the bow impact damage for JEFF(B) are comparable to those for the JEFF(A). Hard structure damage will occur only in the off-cushion, loaded case; even here, it should be limited to less than 1 in. of deflection. Some bow ramp mechanism alignment problems may result, but the craft should not be disabled unless subsequent impacts occur.

SIDE IMPACT

Side-collision response is presented in four groups: (1) on-cushion, loaded; (2) on-cushion, unloaded; (3) off-cushion, loaded; and (4) off-cushion, unloaded. The response was studied for three initial impact locations: Frames 2.5, 8.5, and 12.5 for the JEFF(A) and

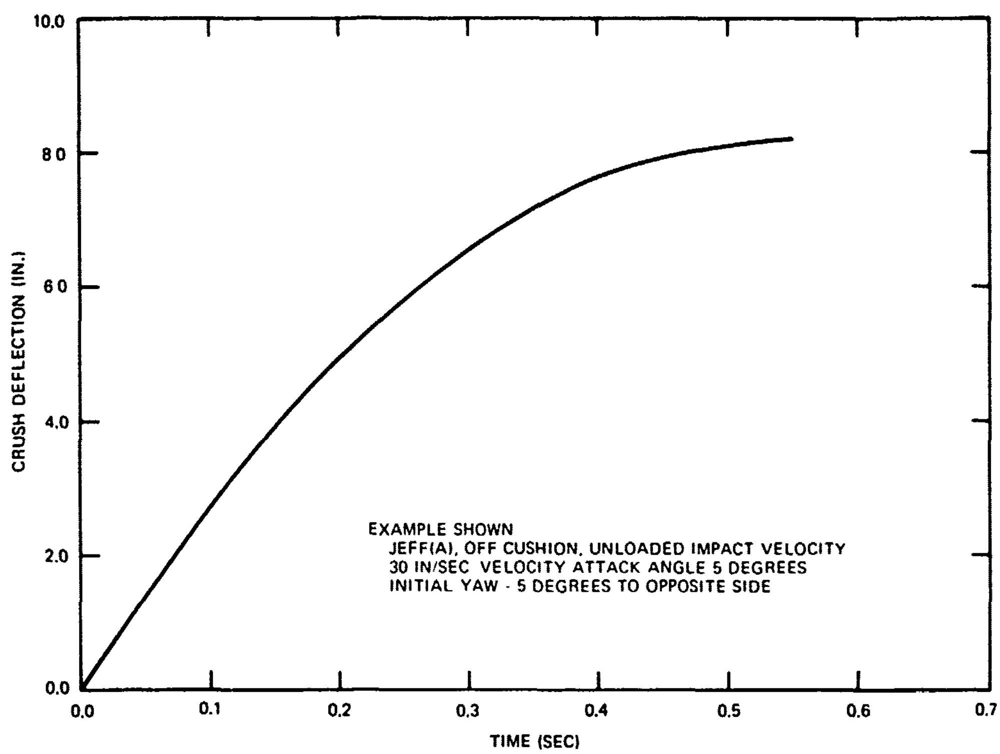


Figure 24 – Typical Time History of the Crush Deflection for a Bow Impact of the JEFF(A)

Figure 25 – Bow Impact Damage Predicted for the JEFF(B)

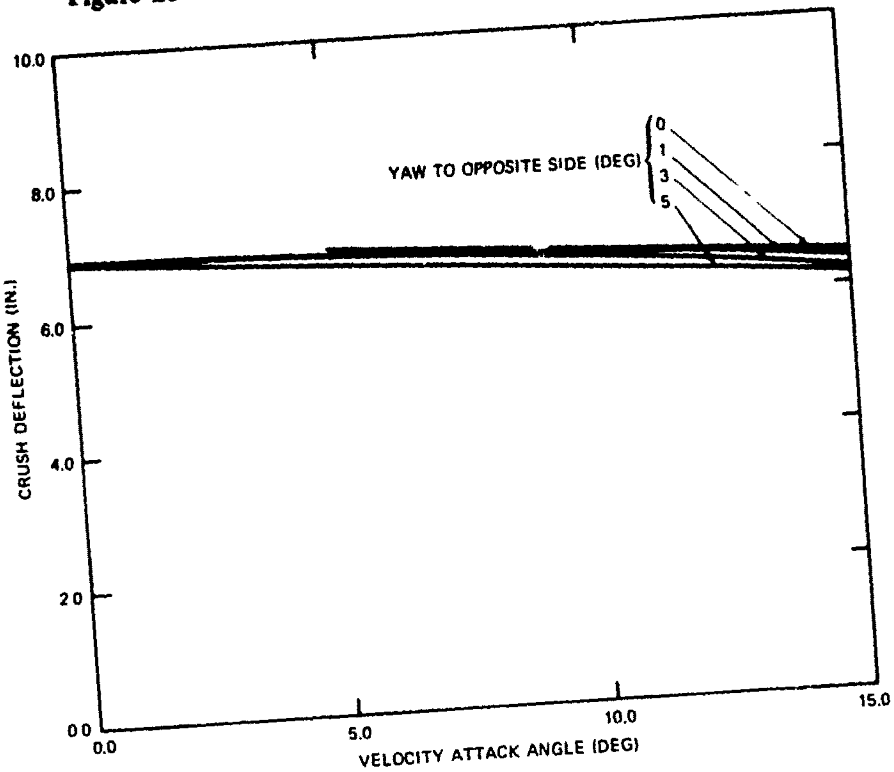


Figure 25a – On-Cushion, Loaded

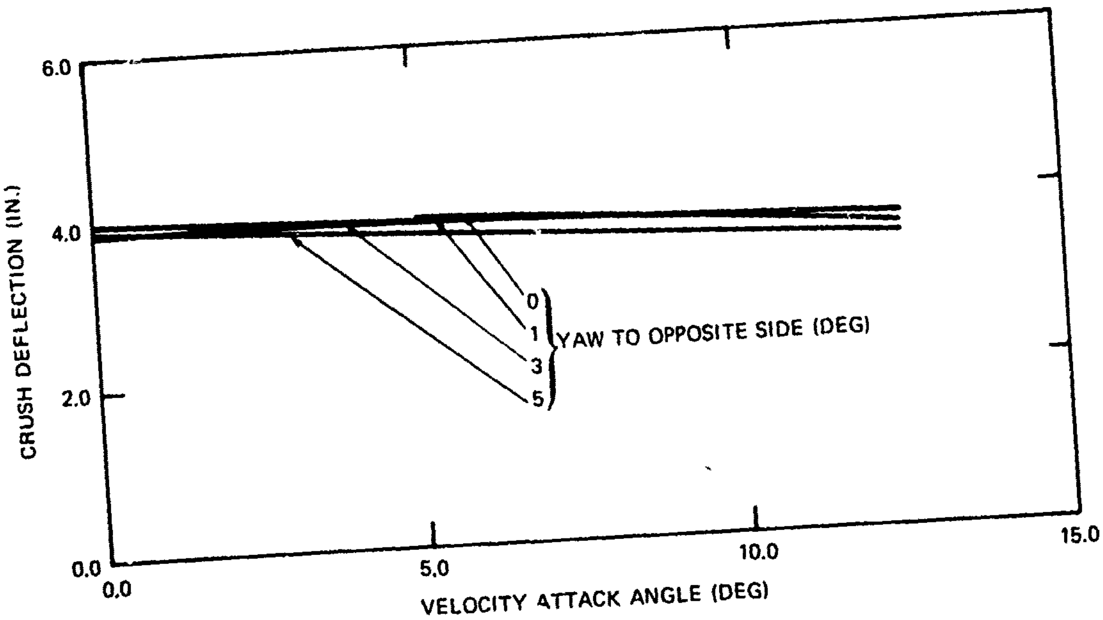


Figure 25b – On-Cushion, Loaded

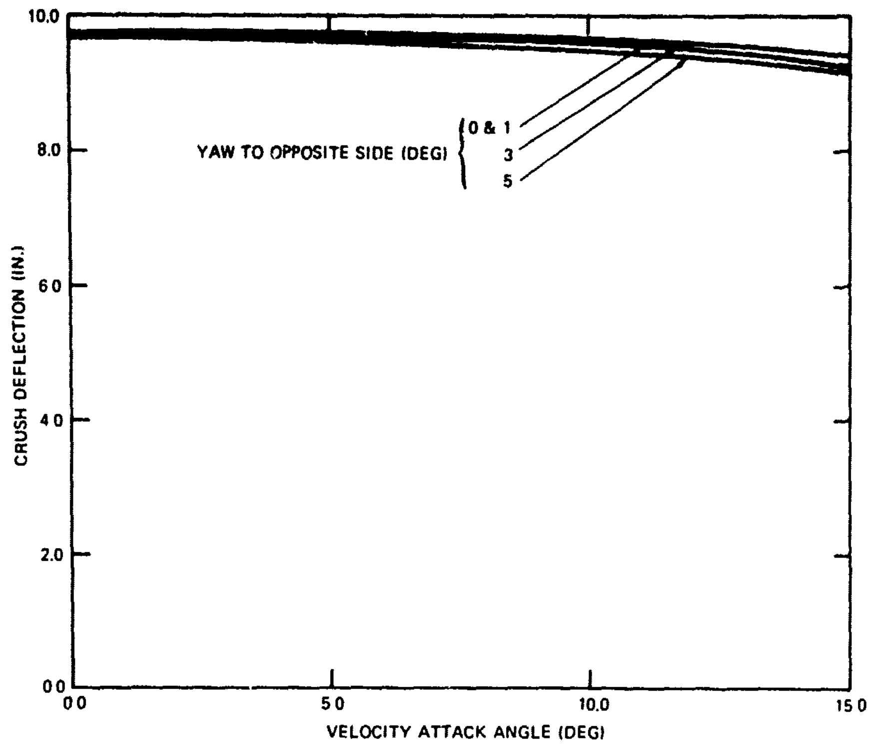


Figure 25c – Off-Cushion, Loaded

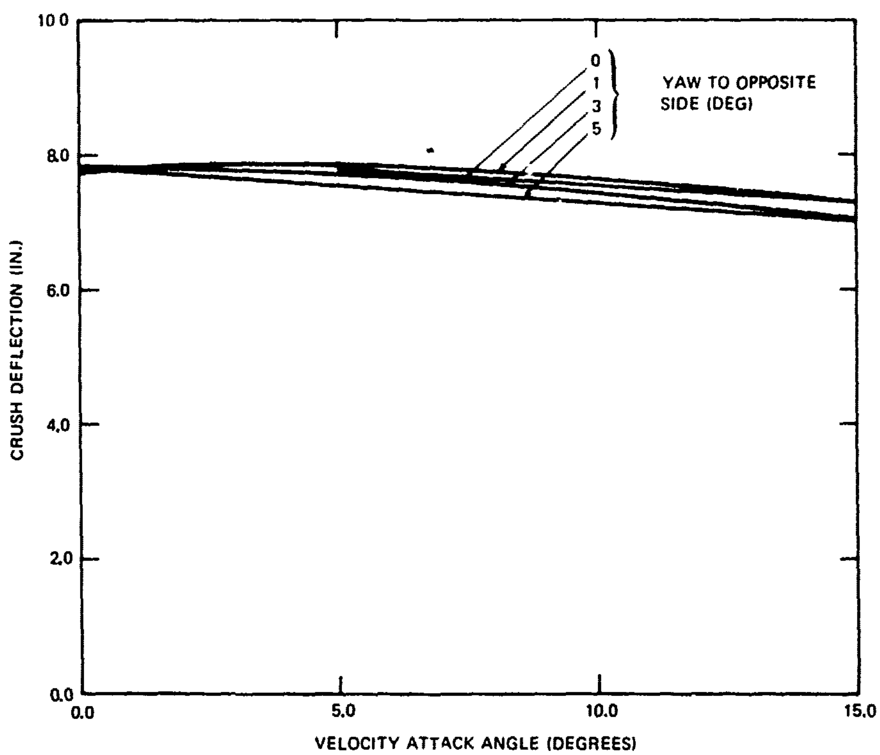


Figure 25d – Off-Cushion, Unloaded

Frames B.5 (midway between Frames A and B), 2.5, and 6.5 for the JEFF(B). Initial contact points were midway between transverse frames. For example, Frame 2.5 refers to an initial contact midway between Frames 2 and 3.

Damage is plotted as a function of velocity attack angle for particular initial yaw angles. Since many different events can happen in side collisions, a set of symbols is used to indicate their occurrences and the figures include a legend to identify the symbols.

In the presentation, note that a separate symbol is used for opposite side collisions and initial opposite side contact. These two events have significantly different effects even though both involve impact of the opposite bow corner of the JEFF with the well deck wall. In the case of initial opposite corner contact, the initial orientation of the craft causes the opposite corner to be deformed to some extent. Since the opposite corner load-deflection curve is assumed to be a plastic function (i.e., does not rebound when contact is broken) the opposite corner must deform further if it is to influence the rigid body motions in the defined collision. In a few extreme cases, the initial deformation of the opposite bow corner is enough to cause hard structure damage at that point. This occurrence is highlighted as a "severe initial orientation." If opposite corner contact occurs at some time *during* a collision, the influence of the resulting loading and motions are significant to the impact point damage. The major differences between *initial* opposite corner contact and opposite corner impact, then, is that in the former, the effects are felt *prior to* the time frame of the collision investigation, whereas in the latter, the effects are felt *during* the time frame of the collision investigation. Of course, it is possible for both cases to occur in a given collision.

A symbol is defined on the figures to indicate when the energy-absorbing bumper is contacted during a collision. Just as for opposite corner contact, it is also possible for the initial orientation of the craft to define initial deformation of the bumper. When this did occur, another computer run was made to redefine the initial orientation of the craft and include the total response of the energy-absorbing bumper. This happened primarily at small initial yaw angles in the off-cushion side impact studies. The re-runs of these cases are referred to as "bumper dominant" cases. Bumper dominant data are very similar to the rest of the side collision data except that the off-cushion, hard structure contact will occur at locations farther aft.

Craft On-Cushion, Loaded

JEFF(A). Figure 26 presents predicted damage to the on-cushion, loaded JEFF(A) for initial side collision contact at the three impact locations. The most important result here is that for initial impact at Frame 2.5, hard structure contact will occur only when both the

Figure 26 – Side Collision Damage Predicted for the JEFF(A), On-Cushion, Loaded

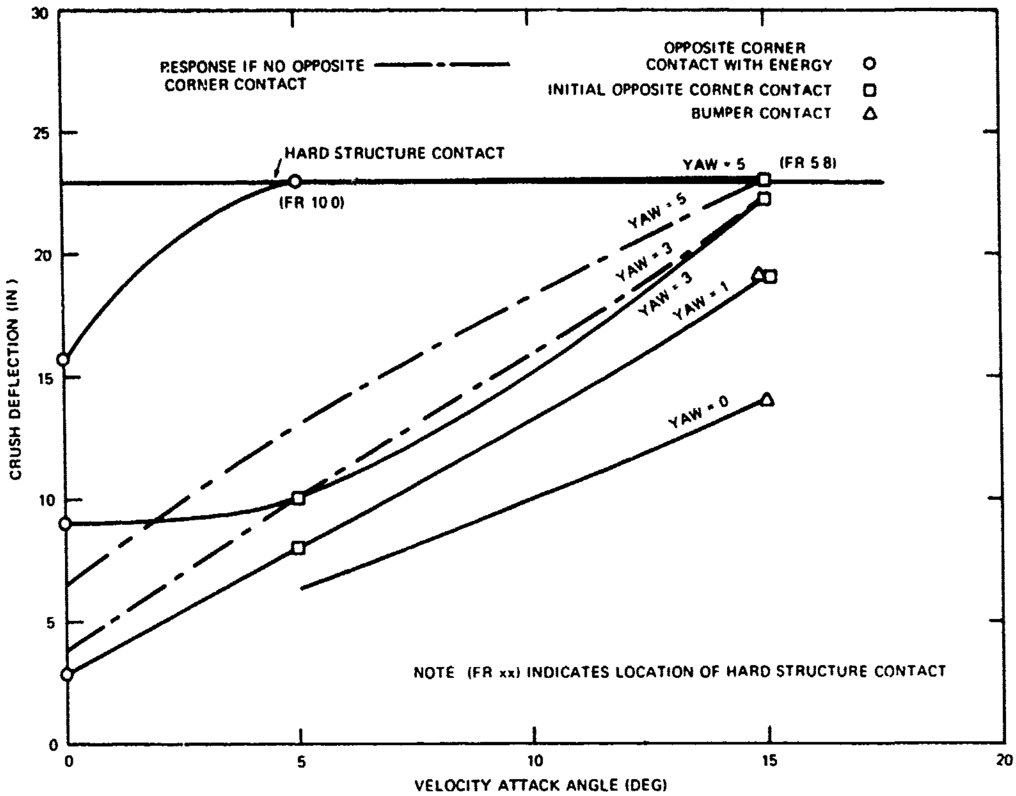


Figure 26a – Frame 2.5

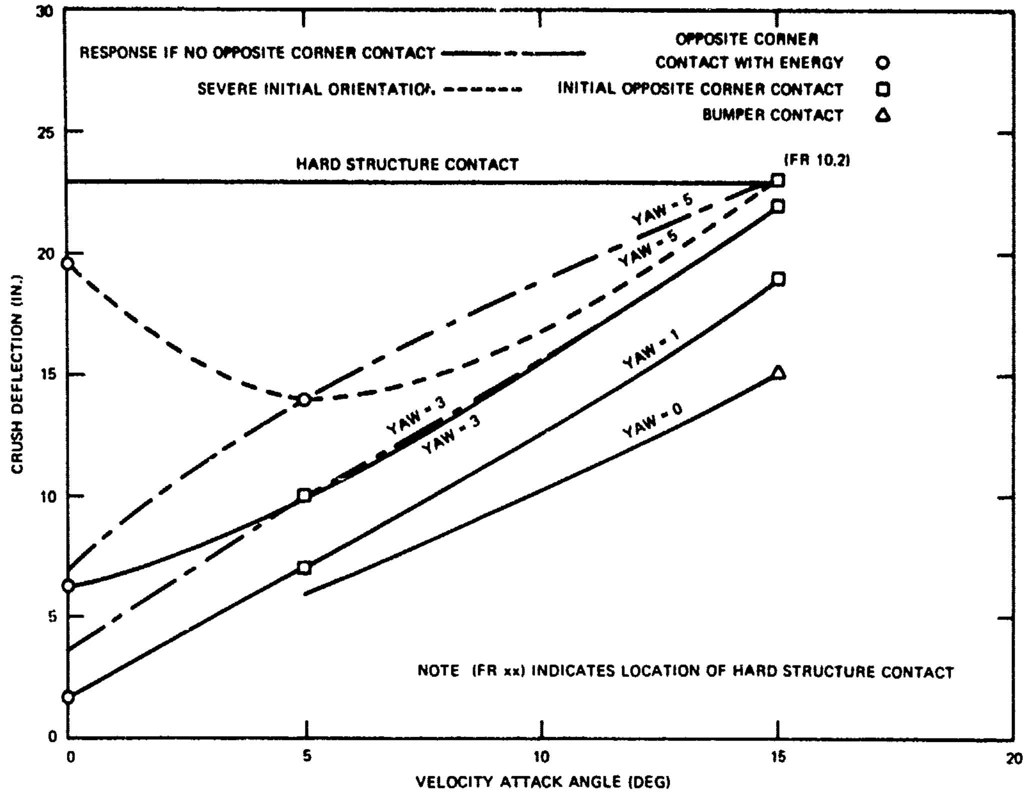


Figure 26b – Frame 8.5

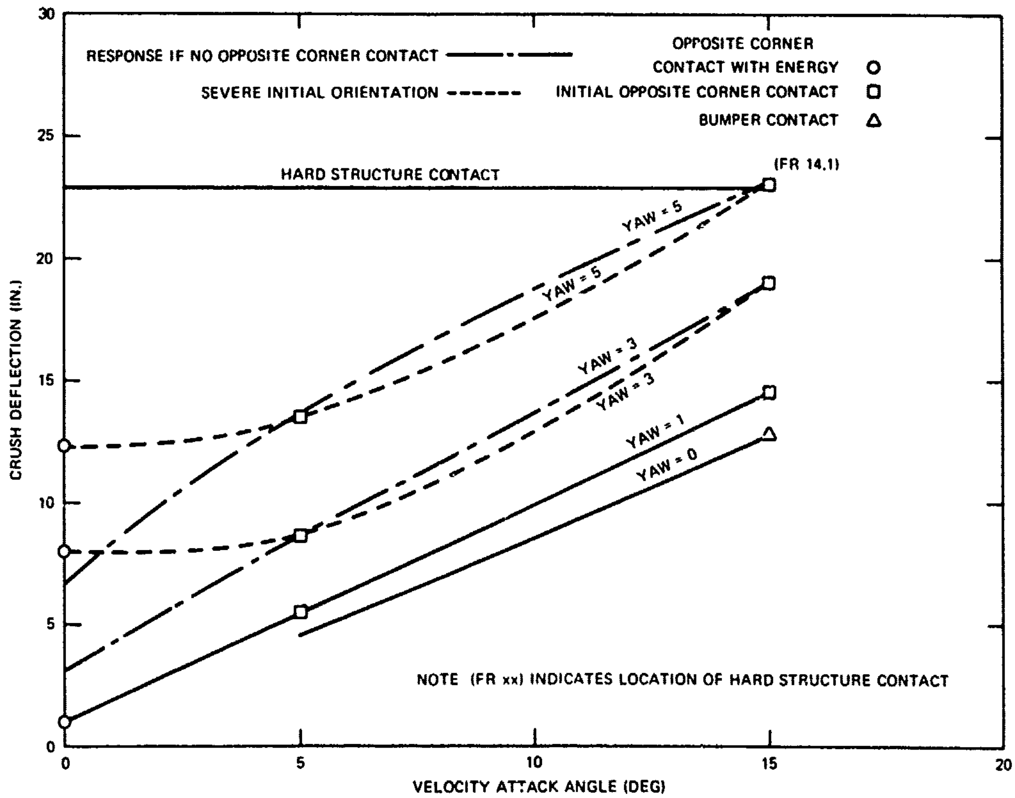


Figure 26c – Frame 12.5

initial yaw angle and the velocity of attack angle are ≥ 5 deg. For initial impact at Frames 8.5 and 12.5, hard structure contact will occur only when the velocity attack angle is 15 deg.

It is interesting to note that when opposite corner collision is not considered, the hard structure would be contacted for the 5-deg yaw angle case only at a 15-deg velocity angle of attack. This illustrates the detrimental effect of contact of the sidewall of the well deck and the opposite bow corner. When the craft rotates, it tends to be better aligned with the well deck, but it is also pushed into the well deck entrance corner on the collision side. Even with hard structure contact, however, crush deflection of the hard structure will be very minor. It is evident that significant deflections of the skirt do occur, especially at high velocity attack angles and high initial yaw angles. Hard structure contact changes the deflection curves drastically because of the relative stiffness of the hard structure and the air bag. Even when the initial impact point is near the bow of the craft, the energy-absorbing bumper will be contacted only at a velocity attack angle of 15 deg and only for low initial yaw angles. When the initial impact point is further aft, the bumper will be contacted even less frequently.

Figure 27 compares the side collision damage of the on-cushion, loaded JEFF(A) as a function of initial impact location for initial yaw angles of 1 and 3 deg. These data also appear in Figure 26, but this form of presentation better illustrates the influence of initial impact location.

Figure 28 illustrates two typical crush deflection time histories for the on-cushion loaded JEFF(A) in a side collision. The upper graph indicates the possible consequences of opposite corner contact during the side collision. The lower graph represents the more common time history, namely, a gradual increase in deflection and a steady decrease in velocity. Most side collisions will last for 2 sec (ranging from 1.5 to 4.5 sec).

JEFF(B). Figure 29 presents the maximum predicted side collision damage to the on-cushion, loaded JEFF(B) for the three locations of initial impact. These results show that hard structure contact is somewhat more likely to occur on the JEFF(B) than the JEFF(A) but that hard structure damage is not significantly different on the two. In other words, when hard structure damage does occur, the magnitude should be about the same on each craft. When comparing side collision damage to the two craft, it should be remembered that initial impact locations are not identical (see Figure 12). Hard structure contact will occur at all yaw angles investigated when impact is for a velocity attack angle of 15 deg at Frame B.5. There will be no hard structure contact when the velocity attack angle is very small, but for initial impact near the bow (Frame B.5), hard structure contact can occur at moderate to low yaw angles (1 to 6 deg). Significant skirt deformation can also occur,

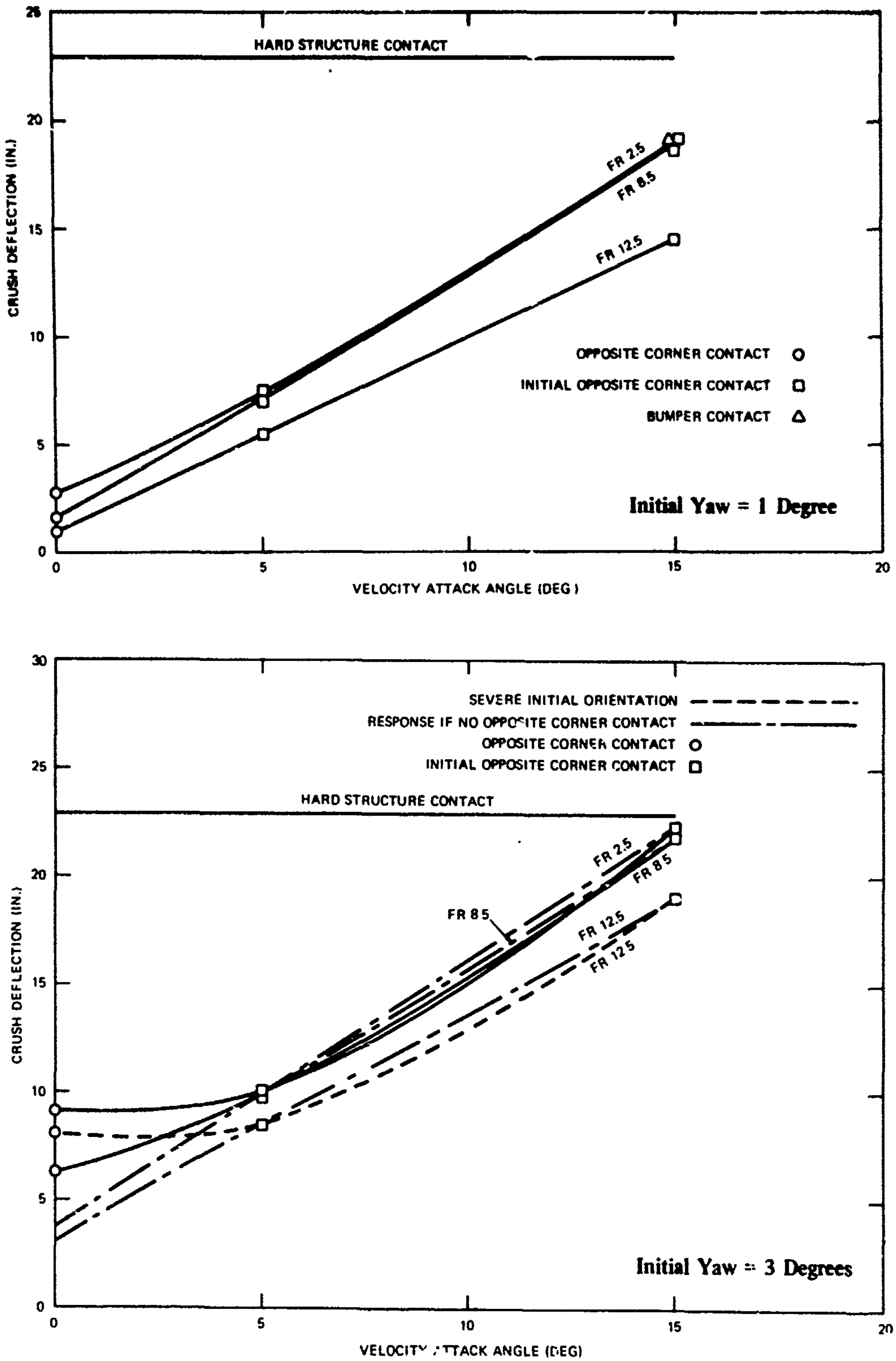
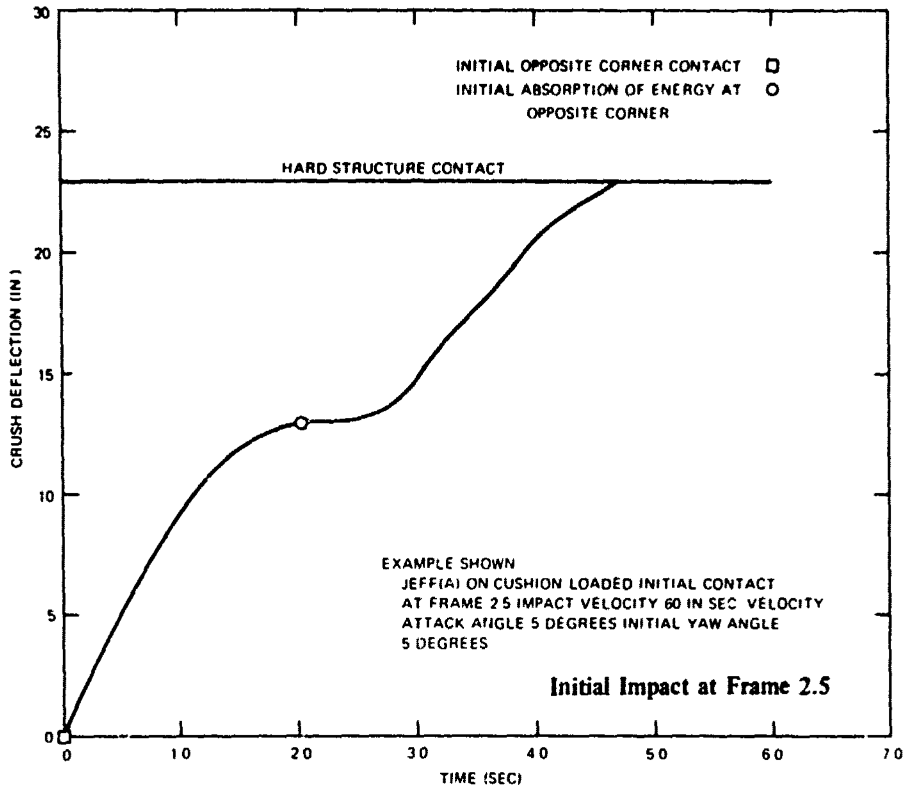


Figure 27 – Influence of Location of Initial Impact on Side Collision Damage to the JEFF(A), On-Cushion, Loaded



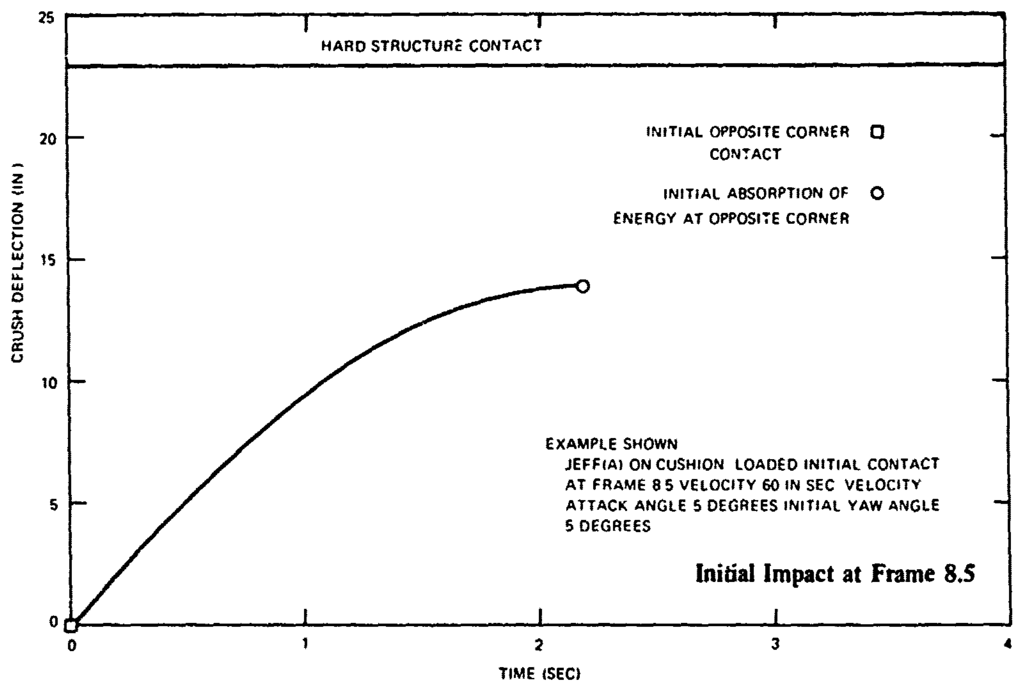


Figure 28 – Typical Crush-Deflection Time Histories for the On-Cushion, Loaded JEFF(A) in a Side Collision

(Both examples are for an impact velocity of 60 in./sec and 5-deg angles of velocity attack and initial yaw)

Figure 29 – Side Collision Damage Predicted for the JEFF(B), On-Cushion, Loaded

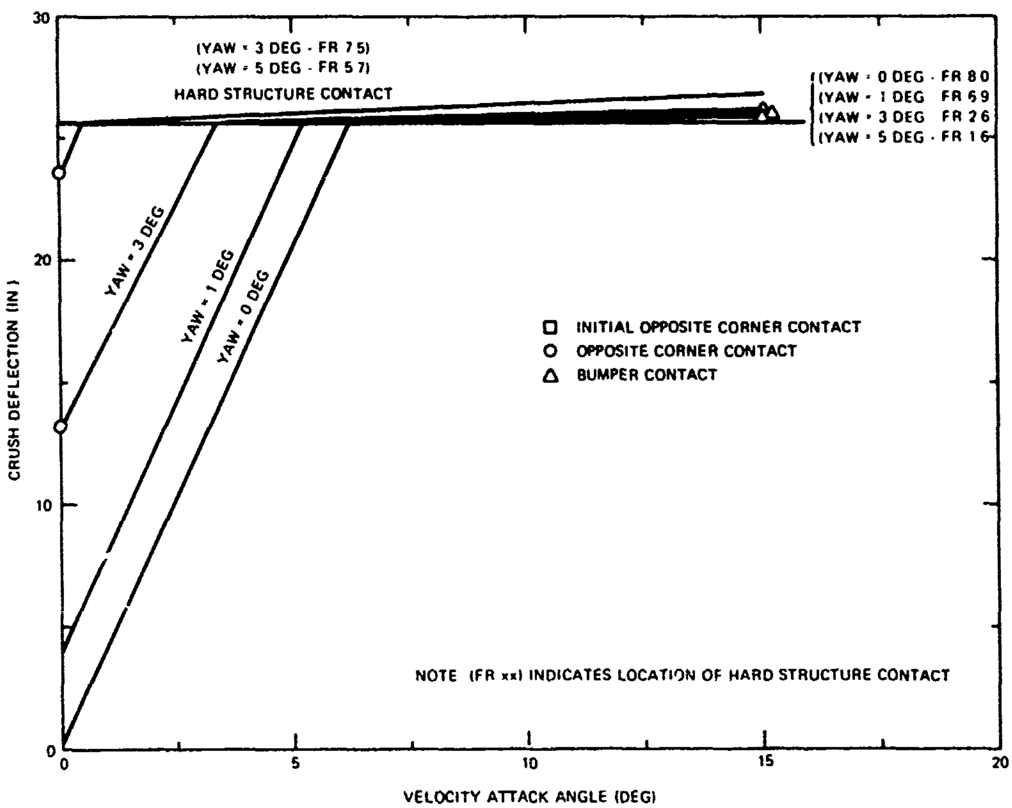


Figure 29a – Initial Impact at Frame B.5

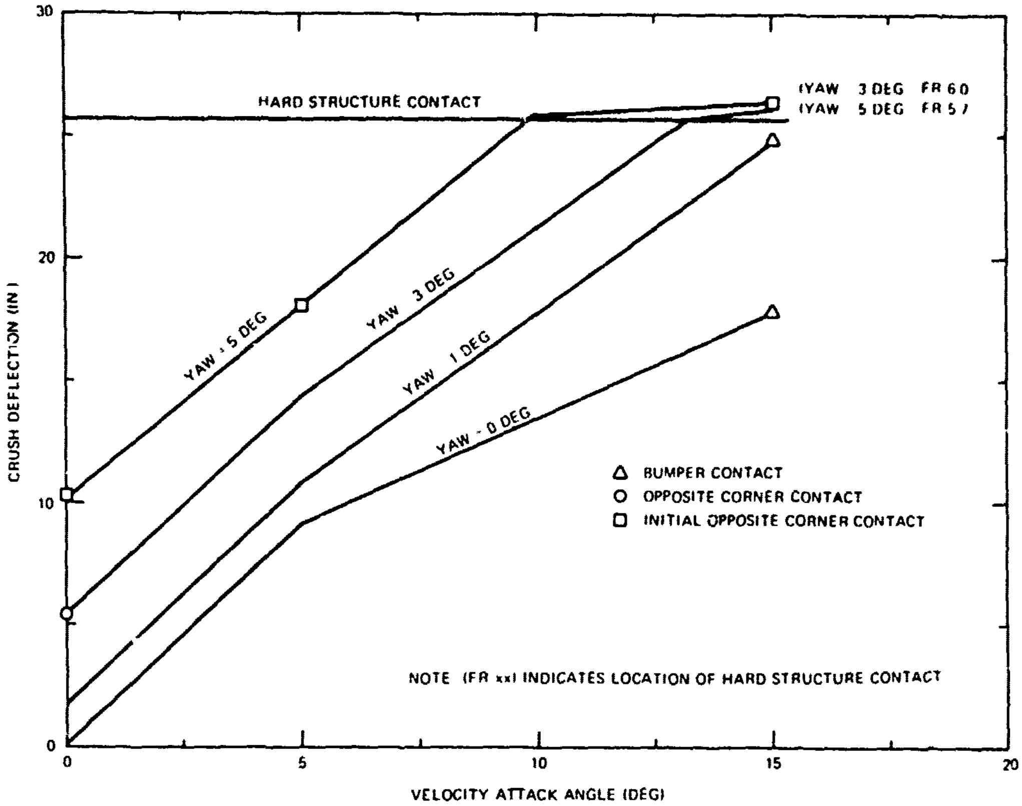


Figure 29b – Initial Impact at Frame 2.5

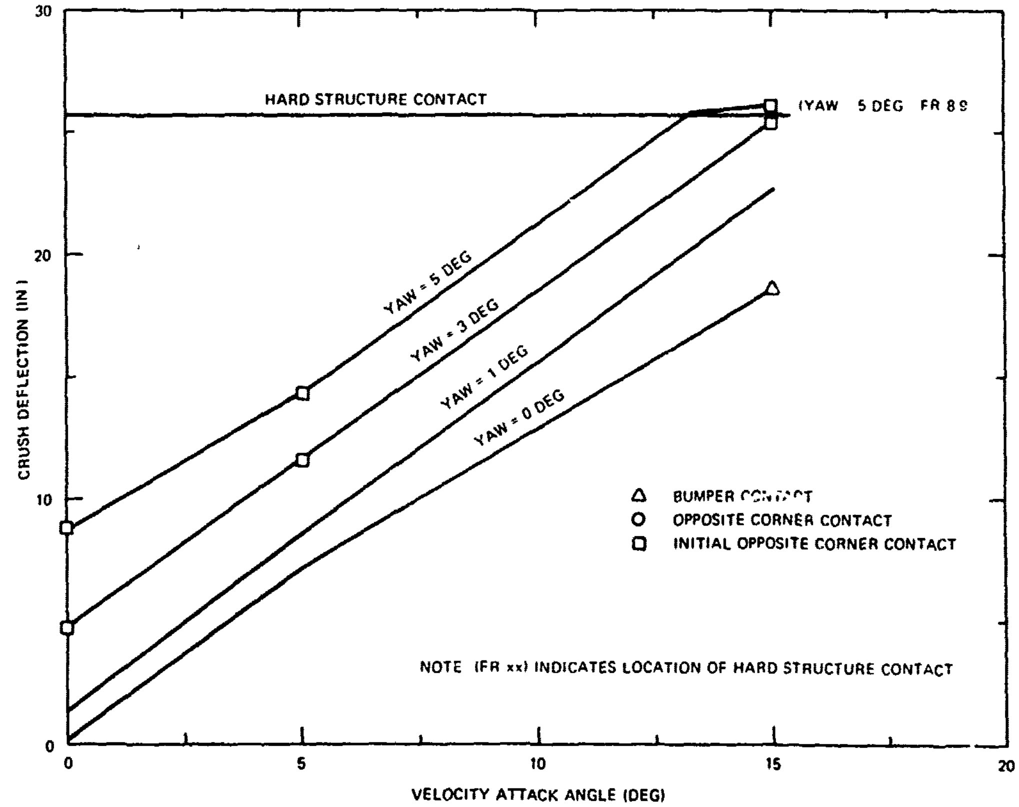


Figure 29c – Initial Impact at Frame 6.5

especially at high velocity attack angles. This may lead to skirt damage as the skirt fabric is forced to conform to the well deck entrance corner and is dragged into the well deck by the craft longitudinal velocity component.

Figure 30 compares the influence of location of initial contact on side collision damage of the on-cushion, loaded JEFF(B) for initial yaw angles of 1 and 3 deg.

Craft On-Cushion, Unloaded

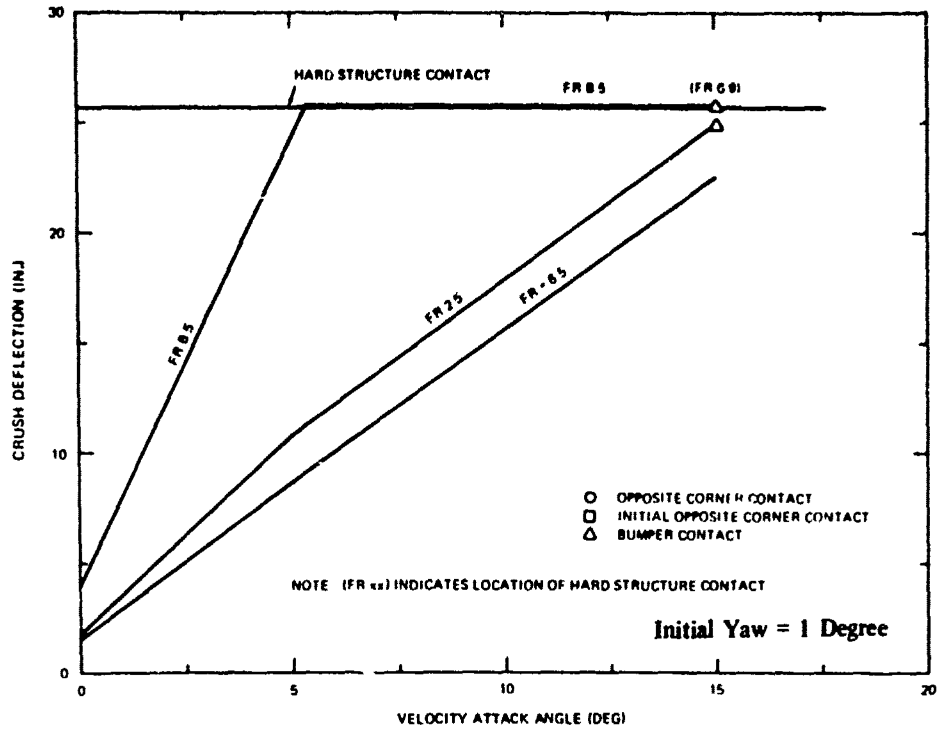
JEFF(A). Figure 31 indicates the predicted side collision damage to the on-cushion, unloaded JEFF(A) for the three initial impact locations. There should be no hard structure contact but there probably will be very large cushion deformation both at high velocity attack angles and also when opposite side contact occurs during a collision. Damage will be less for the unloaded than for the loaded craft. The energy-absorbing bumper did not make contact with the well deck for any on-cushion, unloaded JEFF(A) cases of side collisions investigated either (1) because sufficient energy was absorbed by the cushion to prevent bumper contact or (2) because the cushion crush force caused enough craft rotation to allow the bumper to miss the sidewall of the well deck.

Figure 32 shows the influence of the location of initial impact on side collision damage to the on-cushion, unloaded JEFF(A) for initial yaw angles of 1 and 3 deg.

JEFF(B). Figure 33 presents predictions for side collision damage to the on-cushion, unloaded JEFF(B). As expected, the unloaded craft is not as susceptible to damage as the loaded craft. The only hard structure damage for initial impact points aft of Frame B.5 is for initial impact at Frame 2.5 with a velocity attack angle of 15 deg. Hard structure contact will occur for initial impact at Frame B.5 at high velocity attack angles for most yaw angles and at lower velocity attack angles for high yaw angles.

The likely location for damage from hard structure contact is indicated on the plot as a frame number in parentheses. Although the energy-absorbing bumper will contact the well deck more often on the JEFF(B) than on the JEFF(A), the effectiveness of the bumper must still be questioned. The bumper makes contact only for very high velocity attack angles and the amount of damage does not appear to be significantly altered by the presence of the device.

Figure 34 indicates the influence of location of initial impact on side collision damage to the on-cushion, unloaded JEFF(B) at initial yaw angles of 1 and 3 deg.



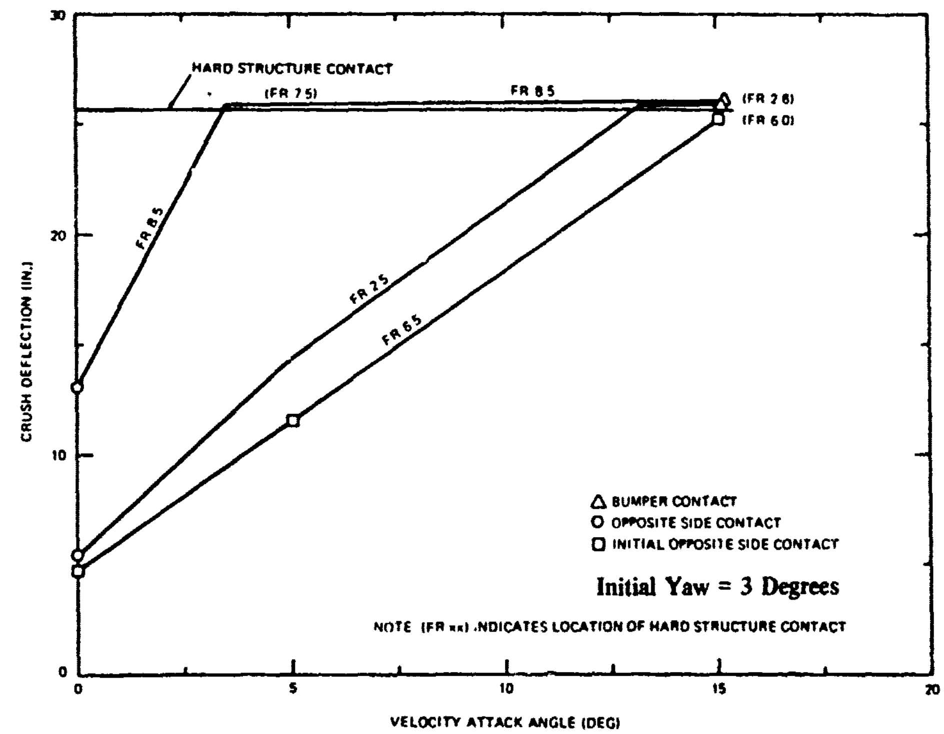


Figure 30 – Influence of Location of Initial Impact on Side Collision Damage to the JEFF(B), On-Cushion, Loaded

Figure 31 – Side Collision Damage Predicted for the JEFF(A), On-Cushion, Unloaded

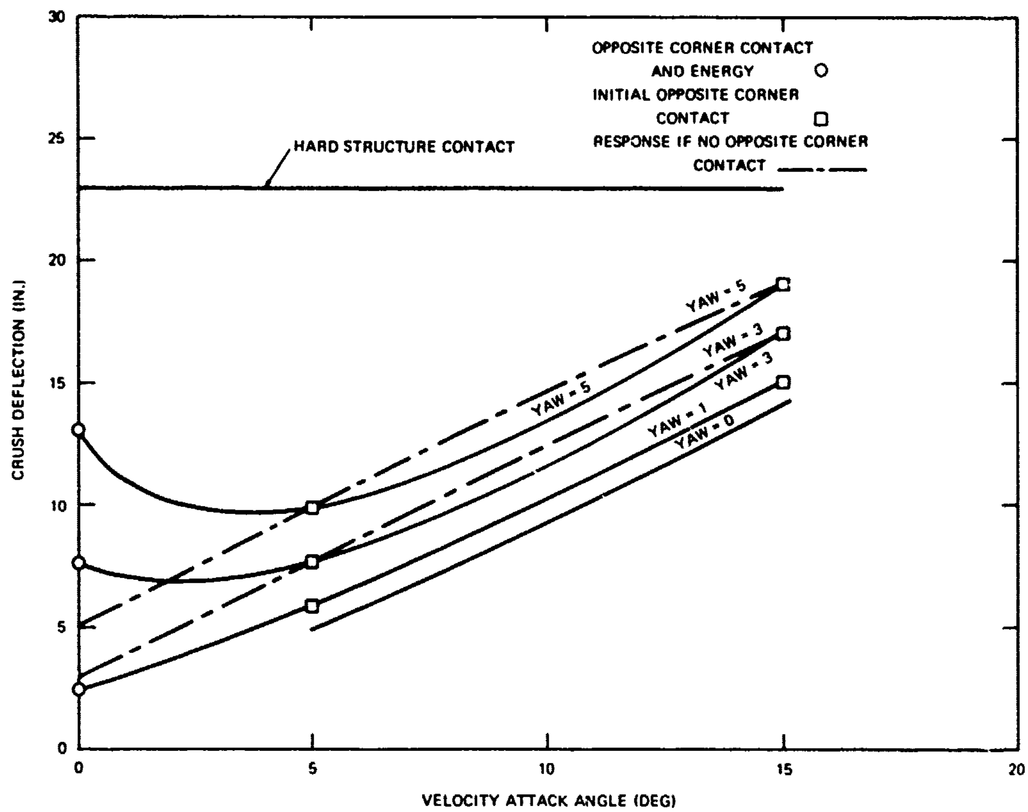


Figure 31a – Initial Impact at Frame 2.5

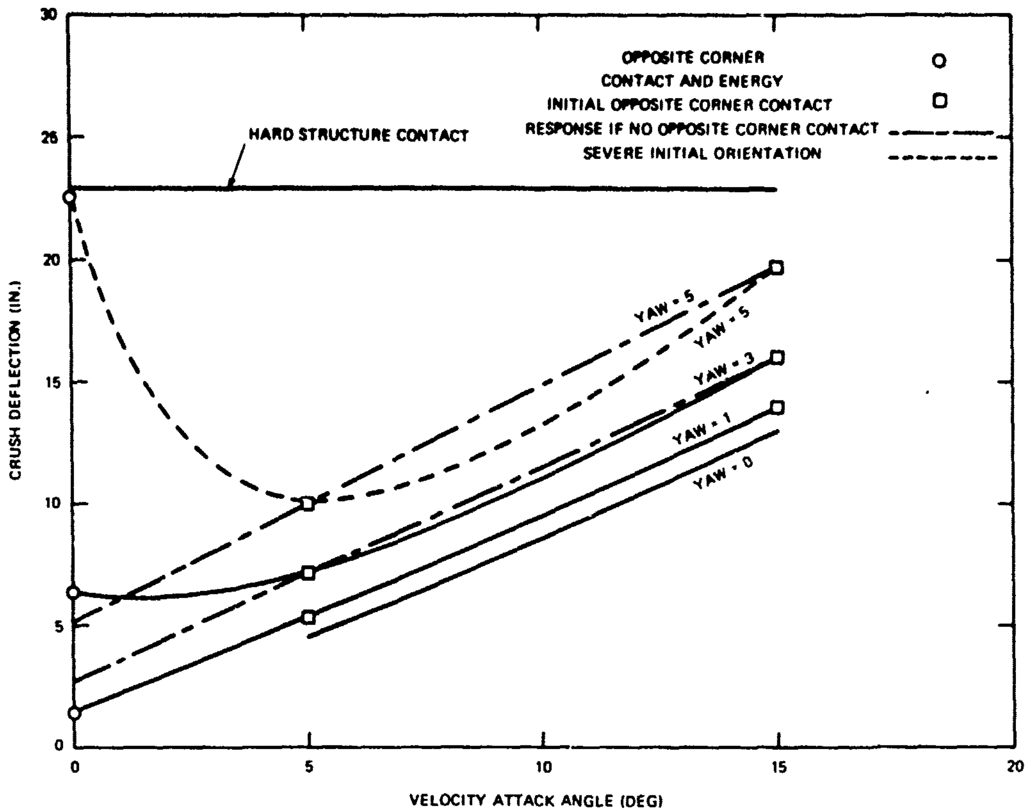


Figure 31b – Initial Impact at Frame 8.5

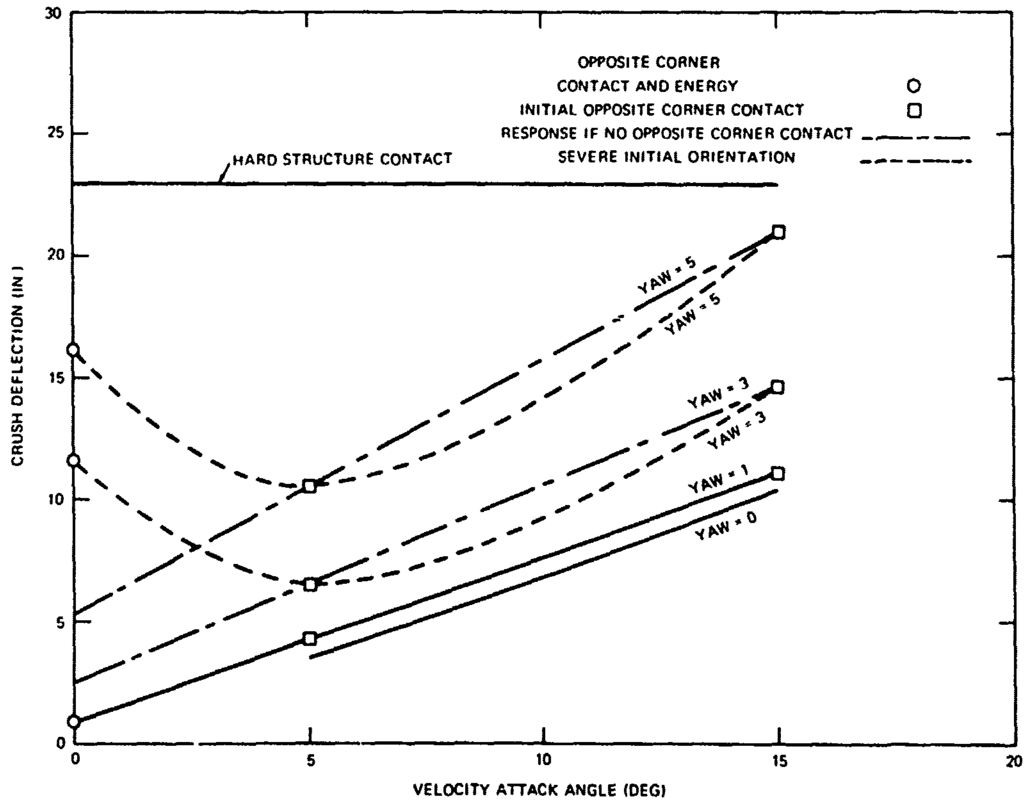


Figure 31c – Initial Impact at Frame 12.5

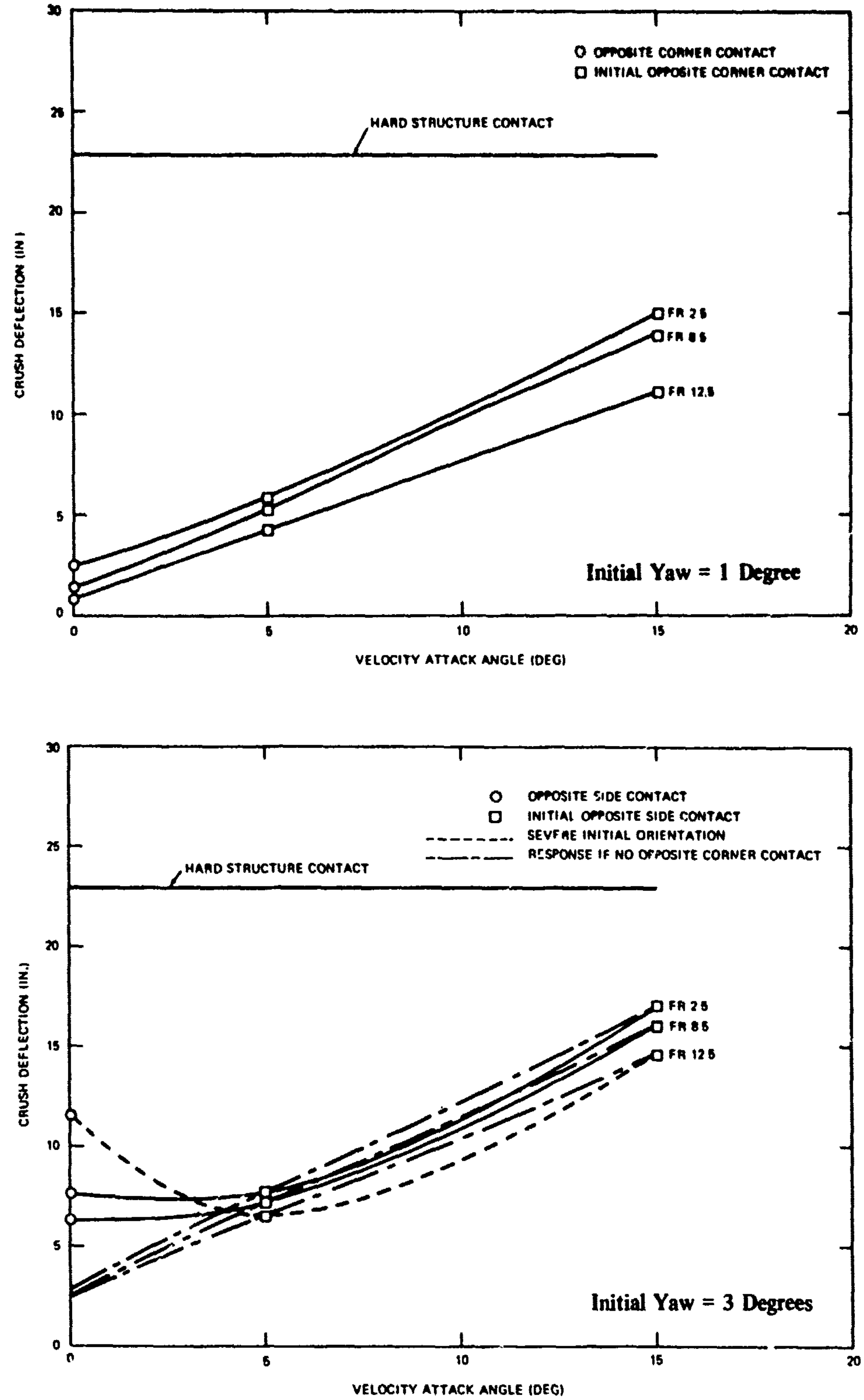


Figure 32 – Influence of Location of Initial Impact on Side Collision Damage to the JEFF(A), On-Cushion, Unloaded

Figure 33 – Side Collision Damage Predicted for the JEFF(B), On-Cushion, Unloaded

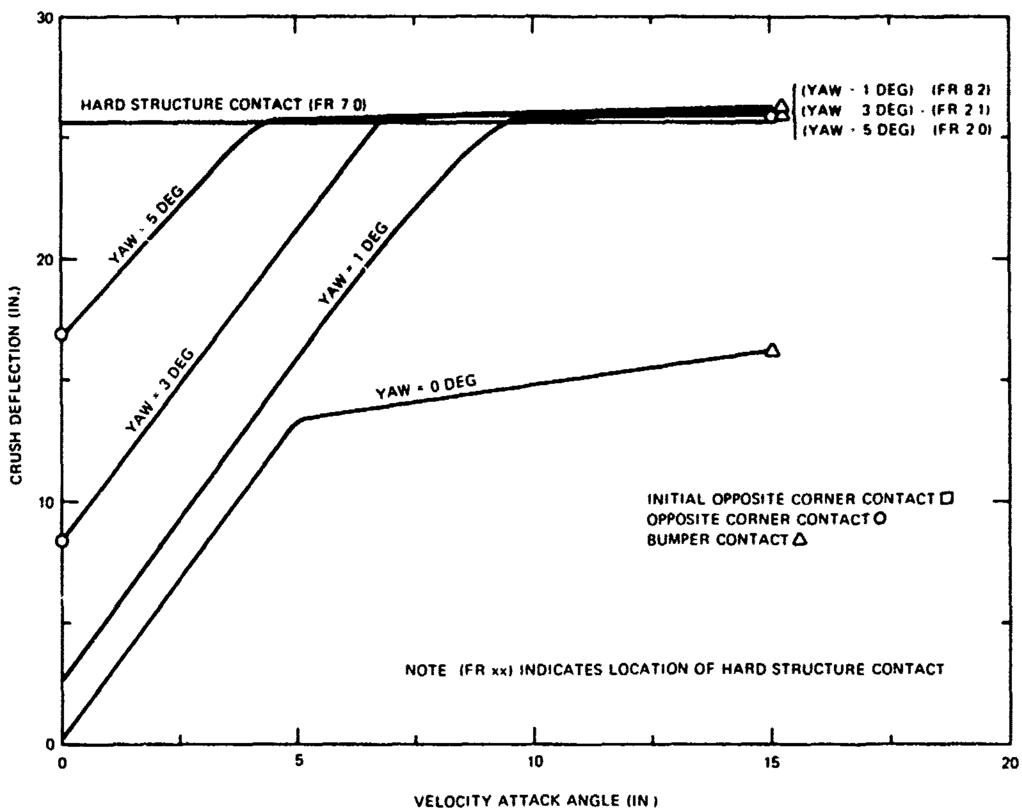


Figure 33a – Initial Impact at Frame B.5

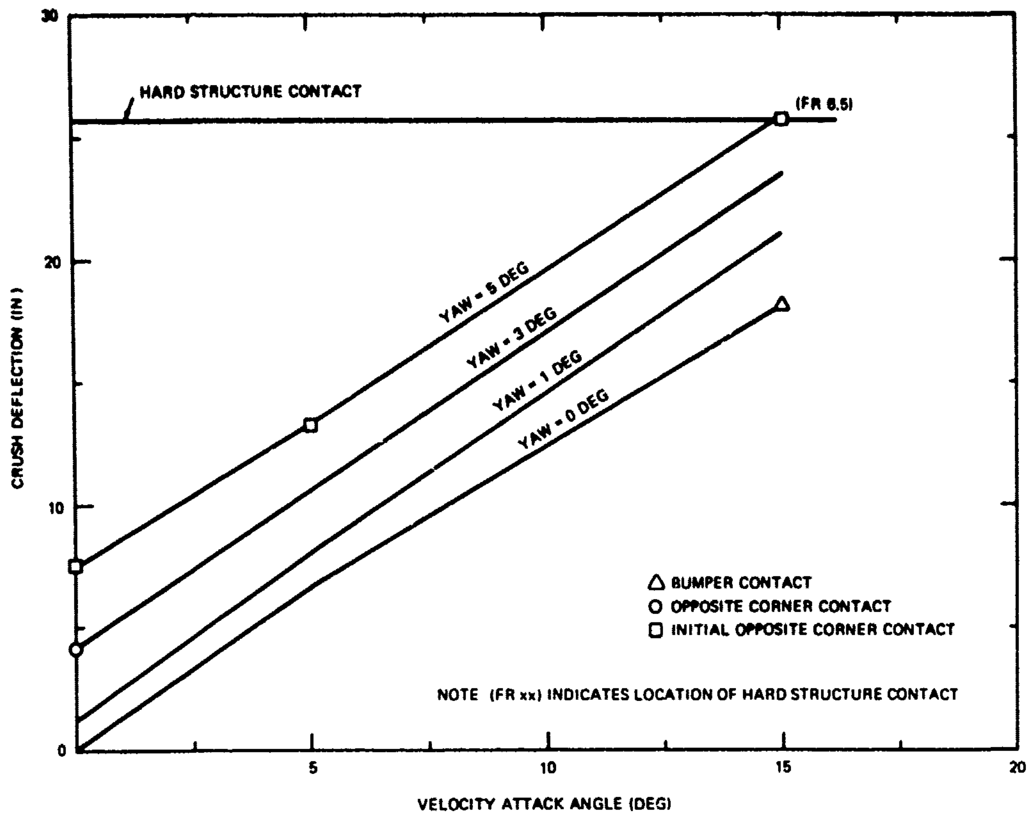


Figure 33b – Initial Impact at Frame 2.5

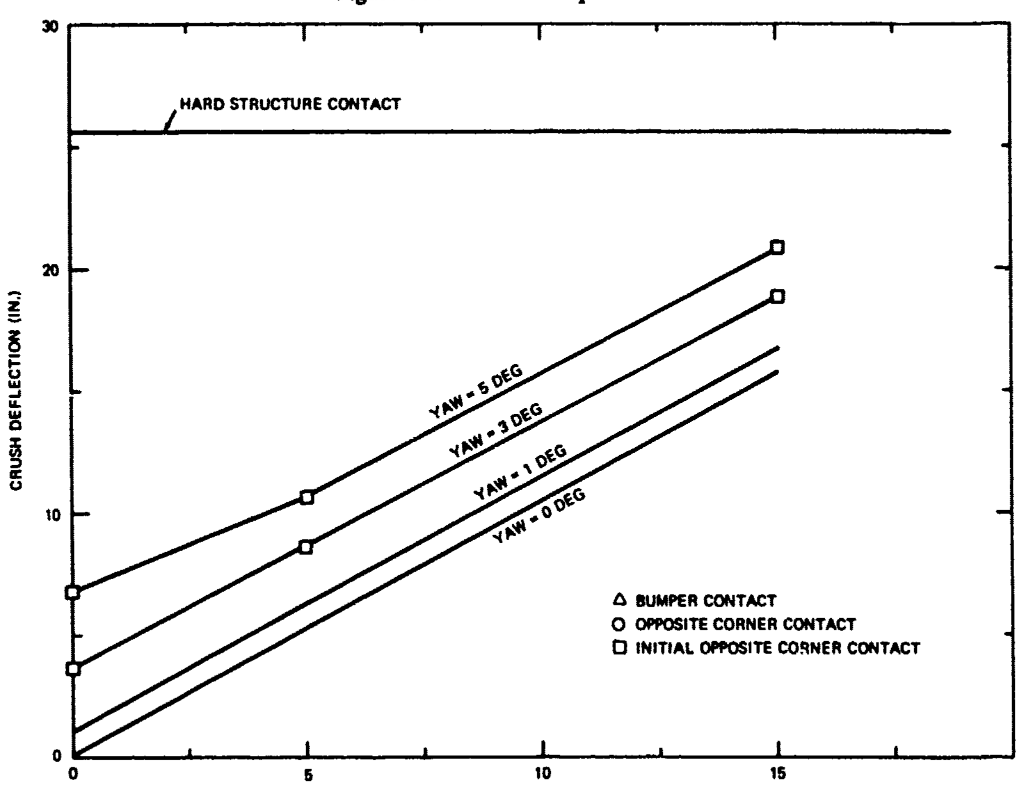
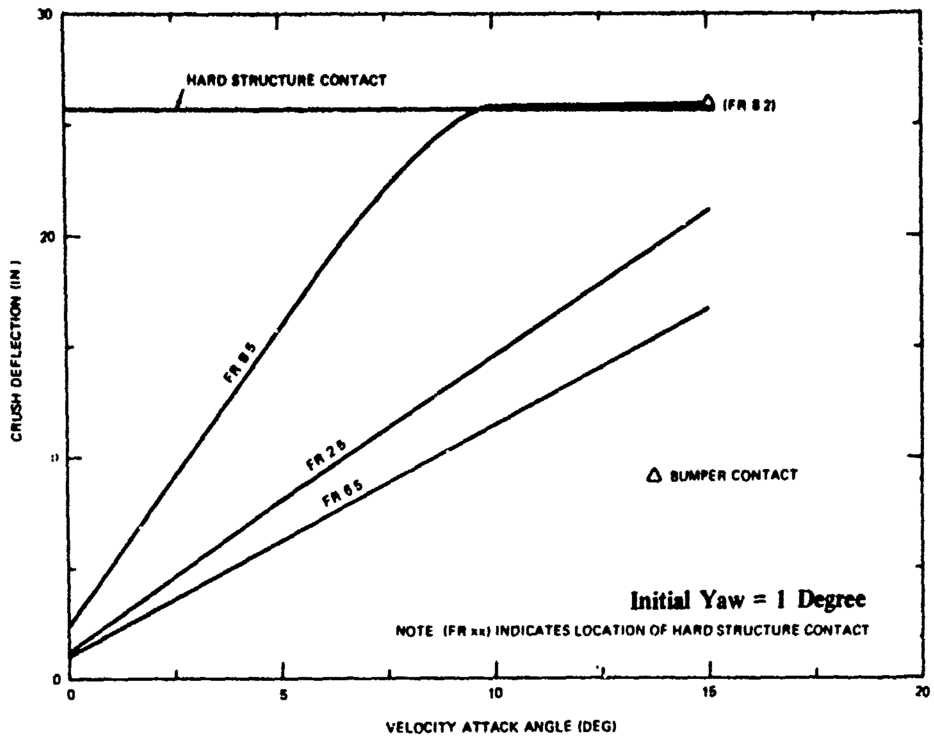


Figure 33c – Initial Impact at Frame 6.5



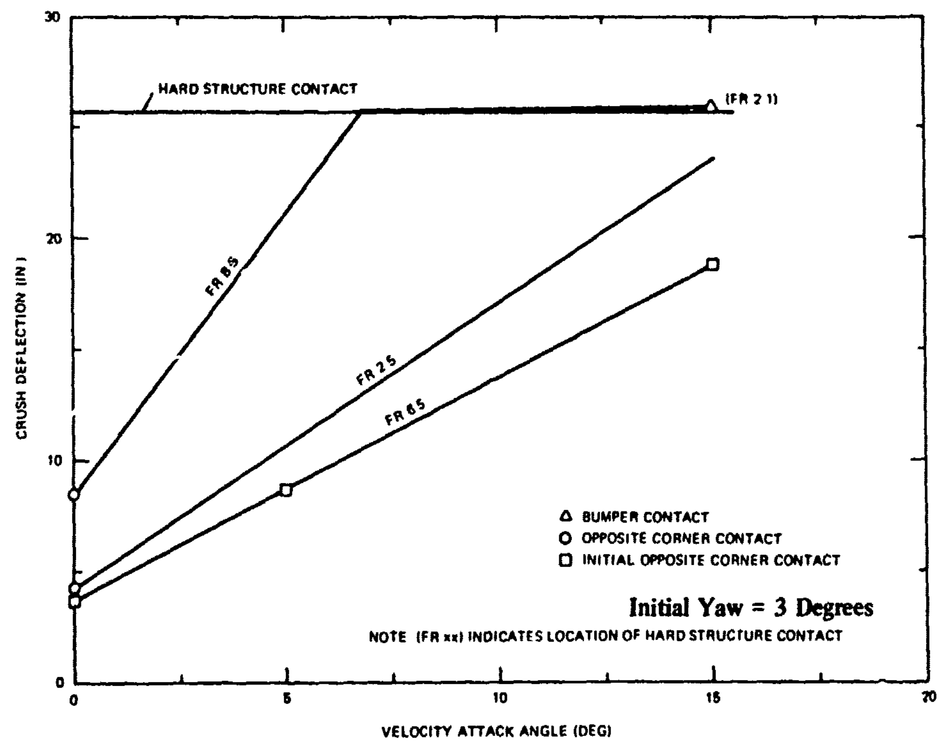


Figure 34 – Influence of Location of Initial Impact on Side Collision Damage to the JEFF(B), On-Cushion, Unloaded

JEFF(A) Off-Cusion, Loaded

Figure 35 presents side collision damage to the off-cushion, loaded JEFF(A) predicted for the three locations of initial impact. For off-cushion collision, the initial contact location was first assumed to be on the hard structure of the craft at the initial impact location. On the basis of these results, it seems likely that the energy-absorbing bumper will initially deform in a large number of cases. Data from the "bumper dominant" runs made later are included in Figure 35. They predict approximately the same damage but the location of the damage is shifted aft.

It is interesting to note that the bumper on the off-cushion loaded JEFF(A) makes contact with the well deck sidewall for initial impact at Frame 2.5 in all off-cushion cases investigated, whereas contact at Frames 8.5 and 12.5 is only at low initial yaw angles.

Side collision damage to the off-cushion loaded JEFF(A) should be reasonably small, limited to 0.5 in. for initial contact at Frame 2.5 and to 1.0 in. at Frames 8.5 and 12.5. The lower damage nearer the bow appears to be a result of higher rigid body rotation for those cases. The higher damage occurred at higher initial yaw angles and at higher velocity attack angles.

Figure 36 presents a typical time history for cases involving crush deflection in an off-cushion side collision of the loaded JEFF(A). This form of impact generally lasts from 30–75 msec, for an average of about 55 msec.

JEFF(A) Off-Cushion, Unloaded

Figure 37 shows the side collision damage predictions for the off-cushion, unloaded JEFF(A) for initial impact at Frames 2.5, 8.5, and 12.5, respectively. The results are very similar to those for the loaded craft but the damage is expected to be approximately 20 percent less than for the loaded case because of the reduced initial kinetic energy of the craft (due to the lower mass).

Multiple Impact during Side Collisions of JEFF(B)

During a side collision, damage to the hard structure is attributable to *initial impact* damage.

On-cushion side collisions may be expected to rebound sufficiently to prevent continuous hard structure contact after initial hard structure damage since on-cushion elastic unloading forces occur as the bag of the skirt system refills.

Figure 35 – Side Collision Damage Predicted for the JEFF(A), Off-Cushion, Loaded

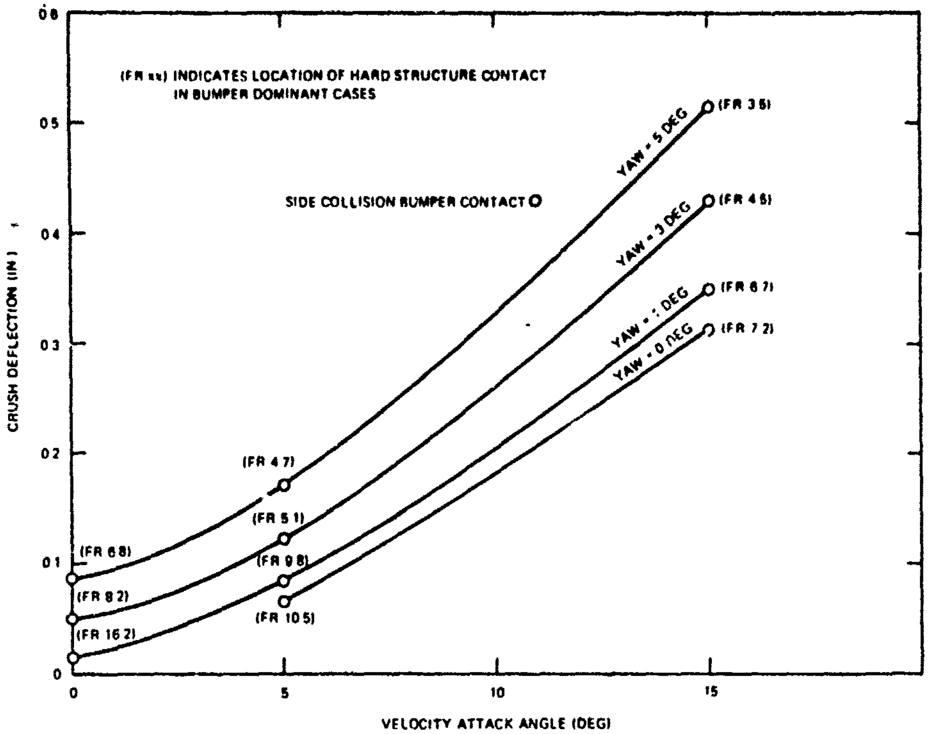


Figure 35a – Initial Impact at Frame 2.5

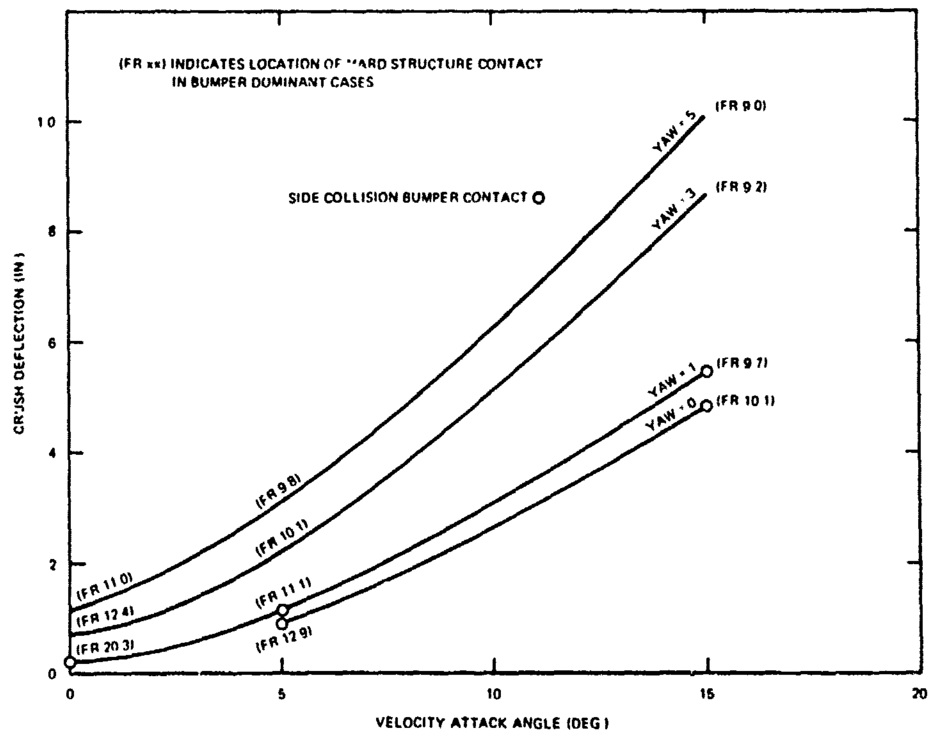


Figure 35b – Initial Impact at Frame 8.5

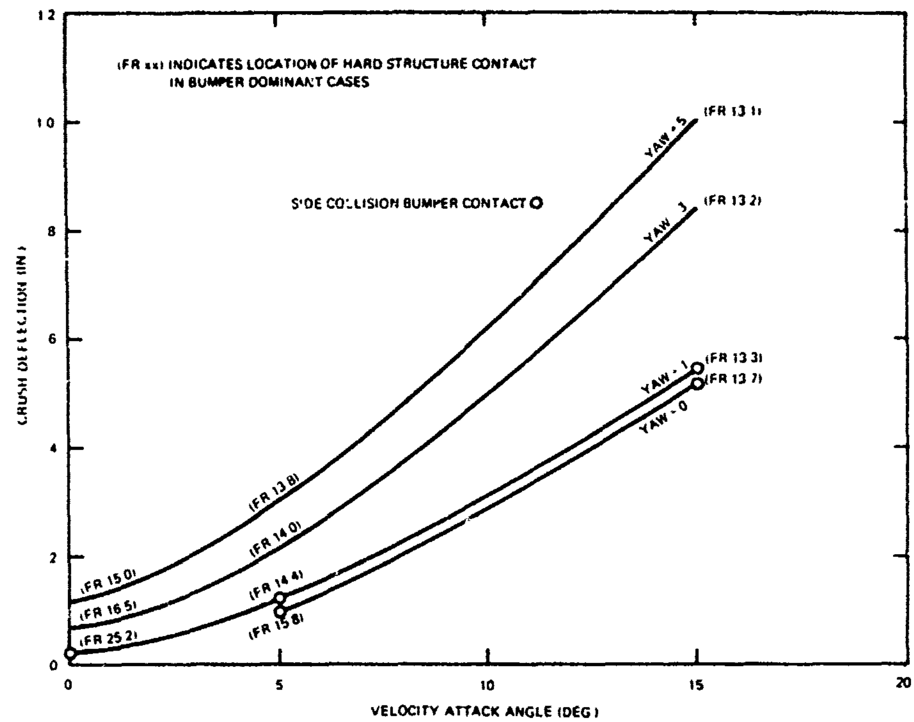


Figure 35c – Initial Impact at Frame 12.5

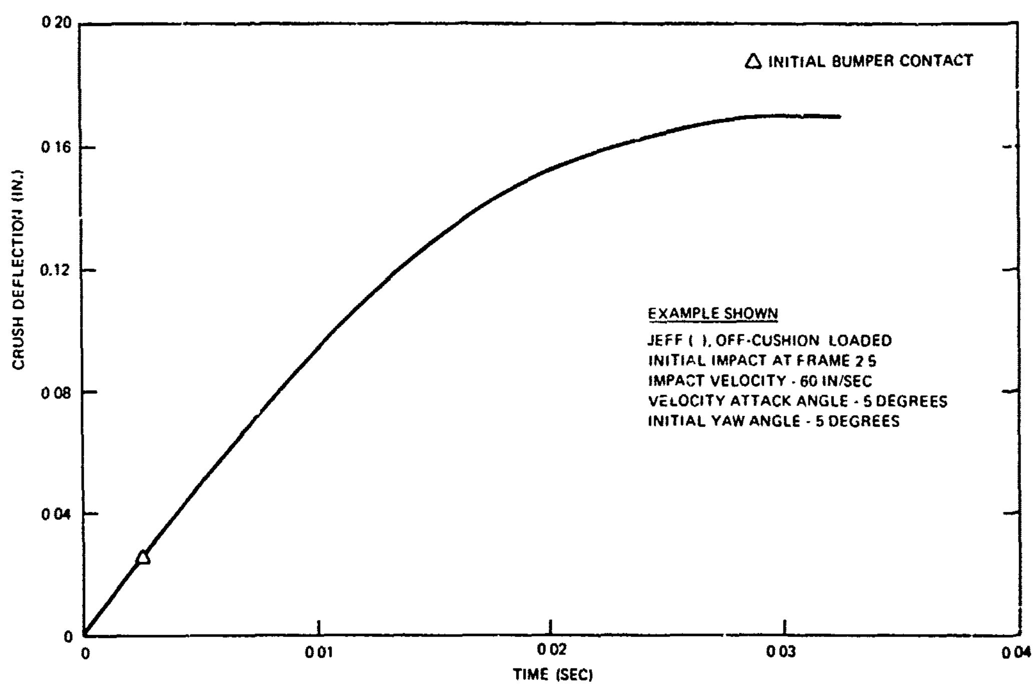


Figure 36 – Typical Time History of Deformation in a Side Collision of the JEFF(A), Off-Cushion, Loaded

Figure 37 – Side Collision Damage Predicted for the JEFF(A), Off-Cushion, Unloaded

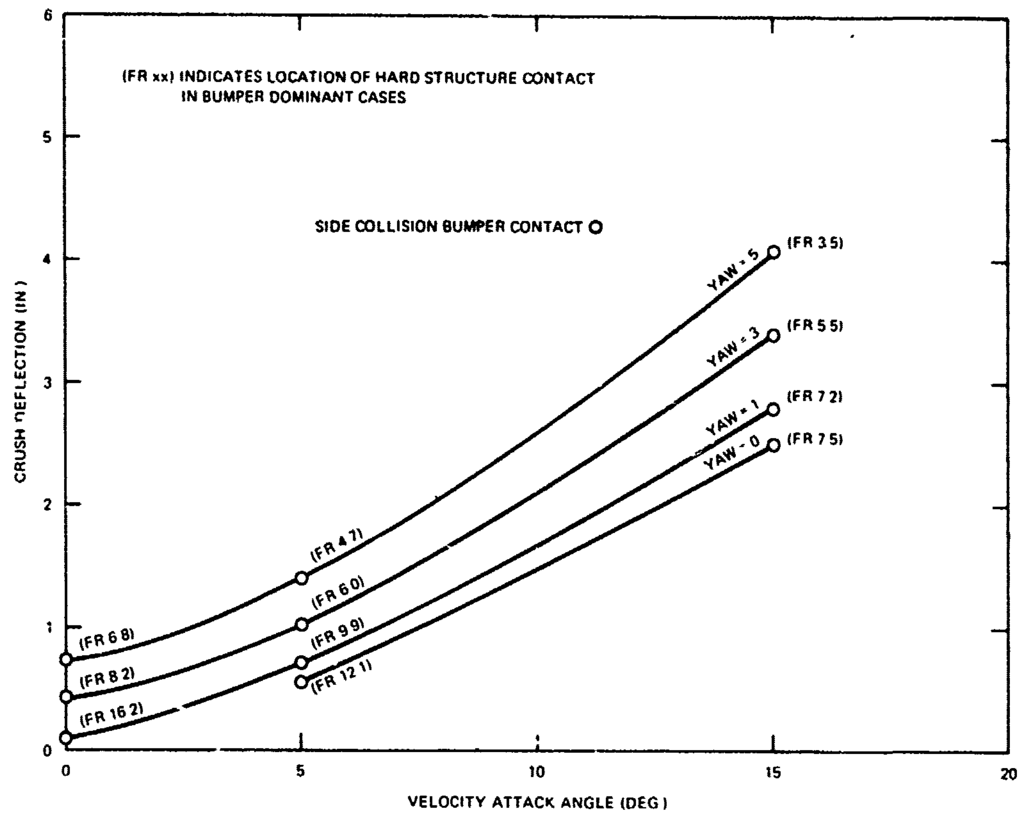


Figure 37a – Initial Impact at Frame 2.5

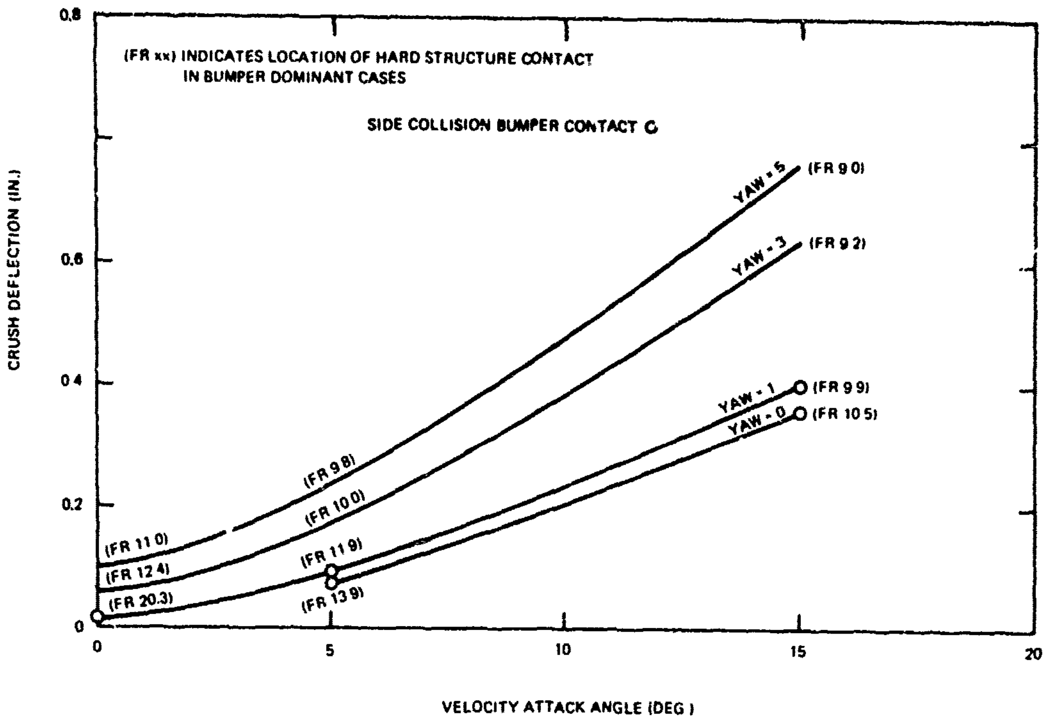


Figure 37b – Initial Impact at Frame 8.5

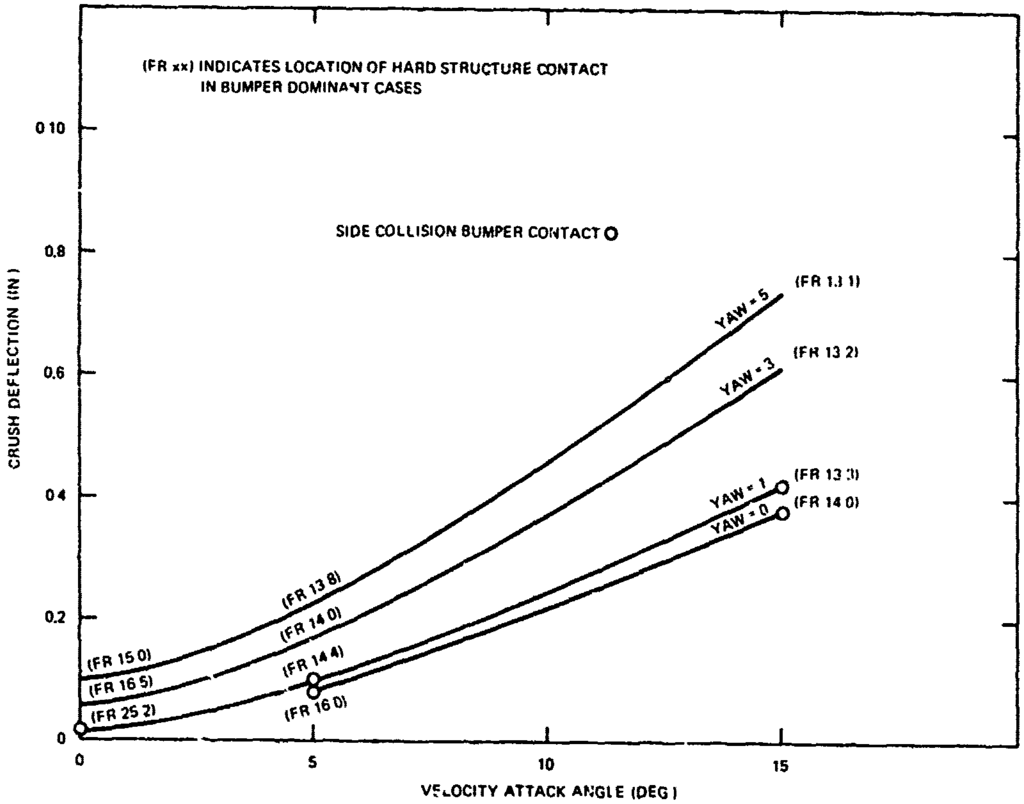


Figure 37c – Initial Impact at Frame 12.5

In most off-cushion side collisions, damage during the initial impact is the most severe, but it is not the only damage. Multiple impact cases investigated for the off-cushion JEFF(B) show that following the initial contact, the side structure makes intermittent, frequent (almost continuous) contact along the side, aft of the initial contact location. In almost all off-cushion cases, the contact will be semicontinuous to the stern. However, in a few cases where the craft is impacted near the bow at a high velocity attack angle, the resulting craft rotation will probably cause the contact to be discontinued forward of the CG location. The illustration of this phenomenon (Figure 38) shows the path traced by the well deck corner relative to the side of the docking JEFF. Continuous contact to the stern will be the more common occurrence, particularly when the collision is perfectly plastic (no elastic unloading). Multiple impact cases with continuous contact to the stern generally take from 8 to 10 sec. During this time, it is reasonable to expect the JEFF helsman to take some corrective actions. The effects of corrective actions are not included in this study.

ROLLED IMPACT

In the case of rolled impact, the top of the frame will collide with the well deck until either the collision energy is totally absorbed or until the craft rolls sufficiently to cause the more substantial structure at the main deck level to come into contact with the well deck sidewall.

For rolled impacts, impact loads are defined by the strength of the transverse frames above the machinery deck (main deck) level. The frame strength is controlled by the sidesway deflection mode or frame racking mode of deflection (Figure 39). Typical values of the load necessary to rack a single frame to the elastic limit are 3.3 kip for the JEFF(A) and 2.0 kip for the JEFF(B). In a collision, however, the top deck and longitudinal stringers distribute even a concentrated impact load to a number of frames. The extent to which the impact load can be distributed depends on the amount of local damage at the impact point, the ability of the top deck to distribute the load in shear, and the strength of the longitudinal stringers near the impact point. By far the most important of these factors is the ability of the top deck to distribute the impact loading. The top deck panel of the JEFF(B) is a composite panel whereas that of the JEFF(A) is a conventional longitudinally stiffened plate. Both are capable of carrying significant shear loading. It appears reasonable to expect a crush loading of about 20 kip at the top of the frame in each case. Crush loads of 20 and 50 kip are compared later to evaluate the effect of the crush loads on craft response during rolled impact.

Figure 40 defines the impact conditions under which the rolled-impact collision ends in each of these two modes. Main deck contact will occur at low initial roll angles and at low

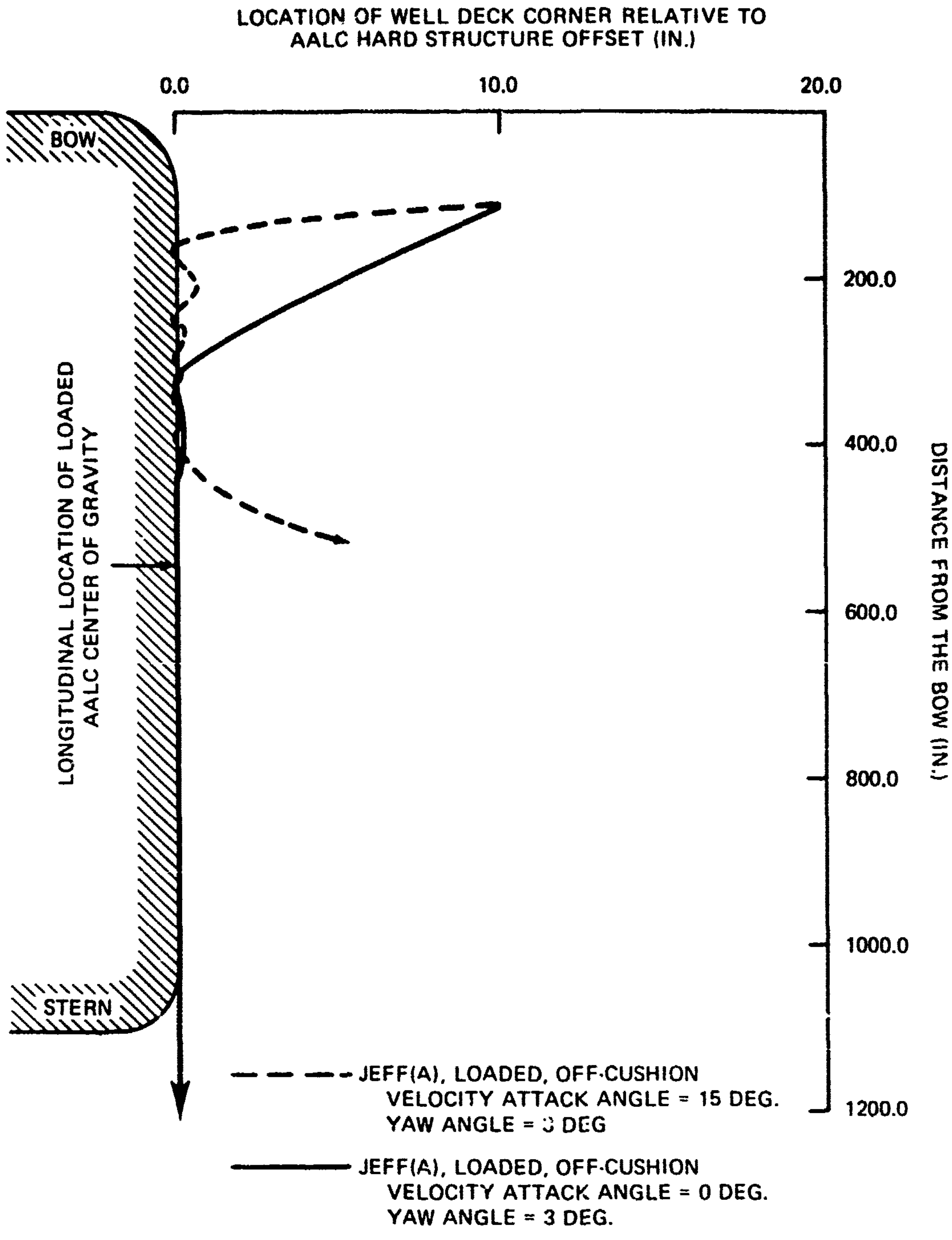


Figure 38 – Path of the Well Deck Corner in Off-Cushion, Multiple Impact

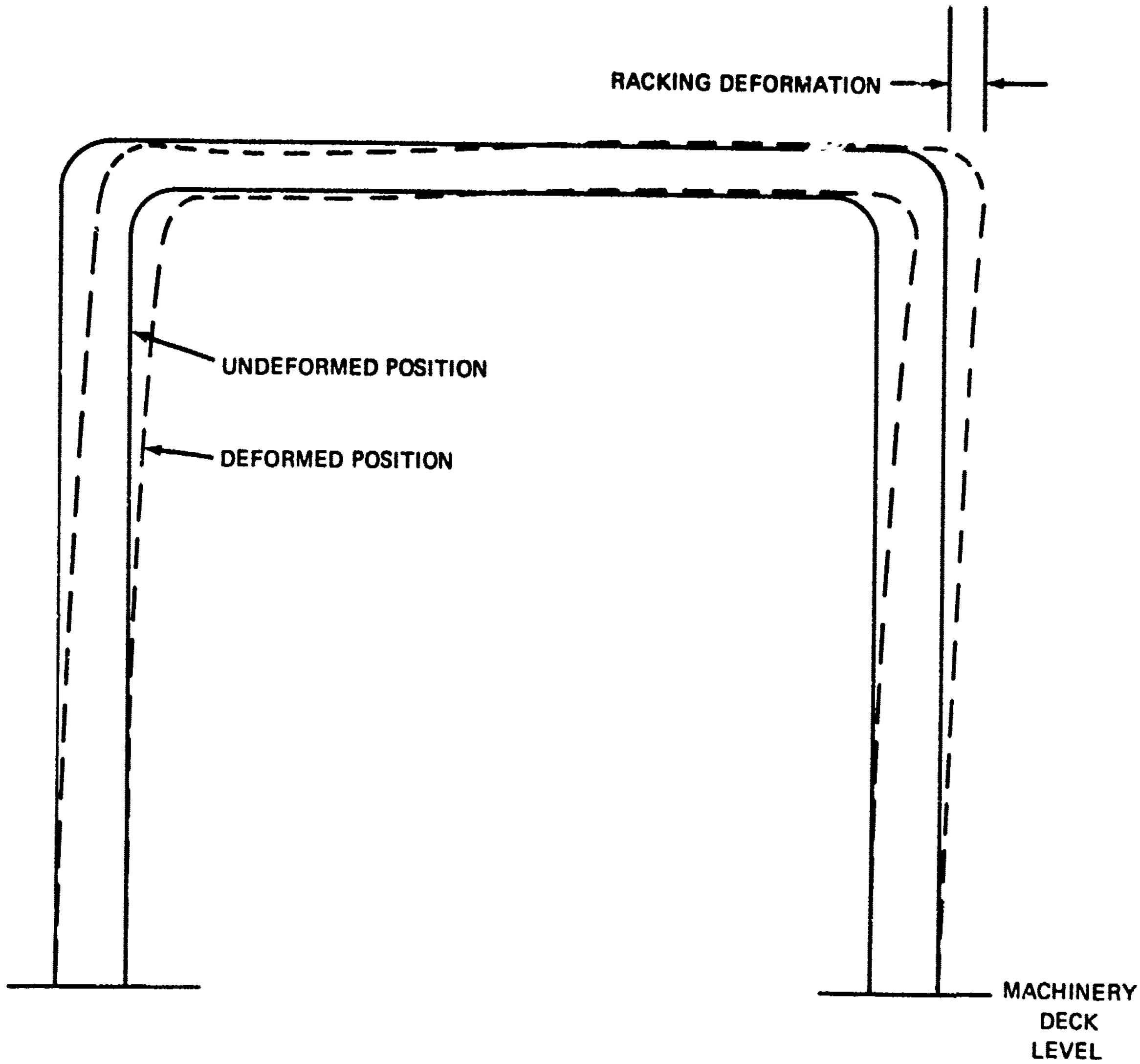
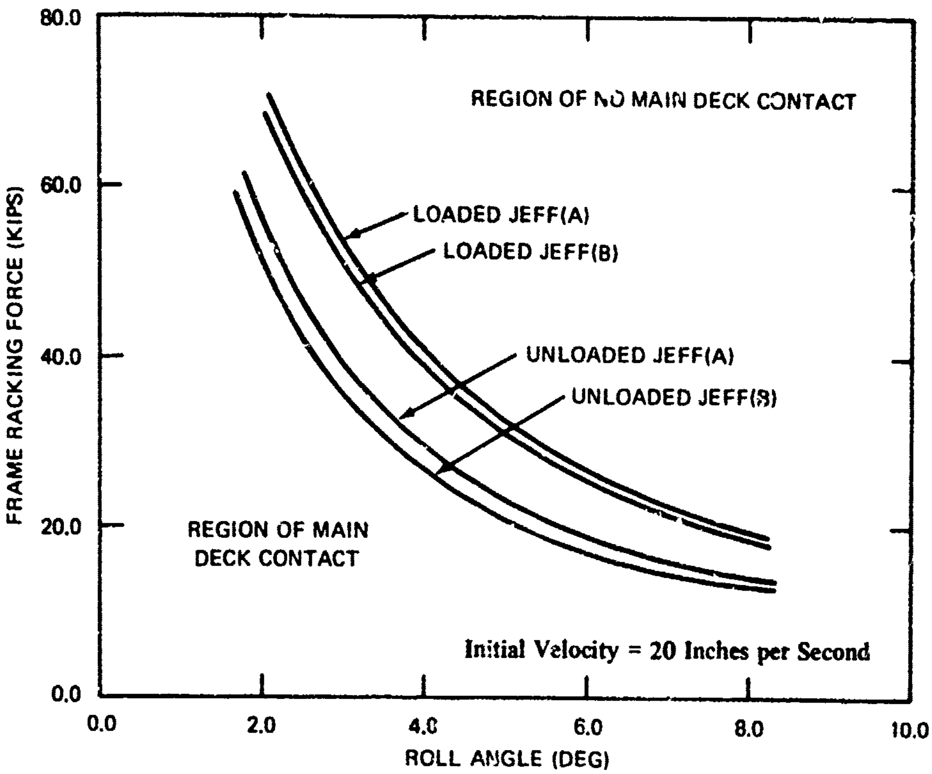


Figure 39 – Frame Racking



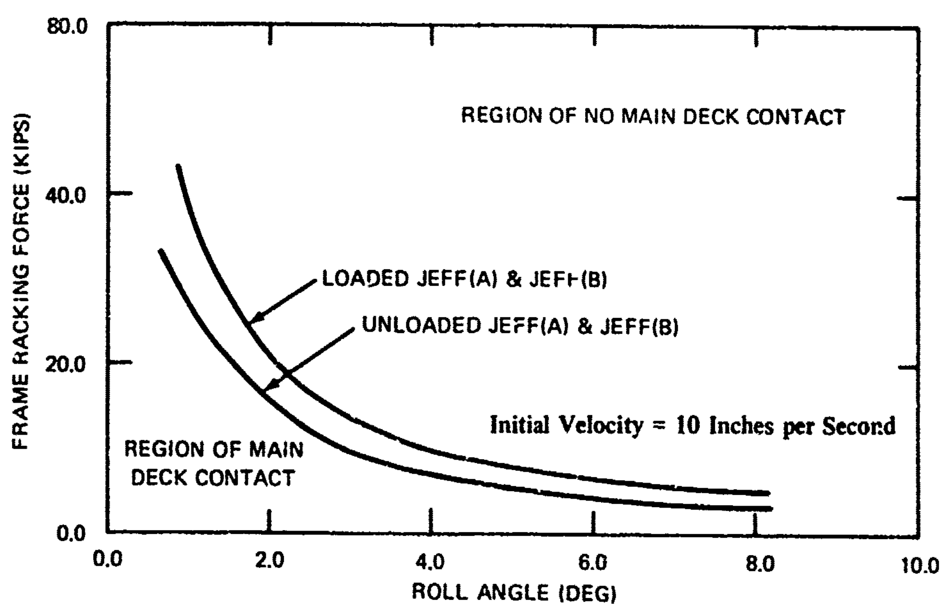


Figure 40 – Rolled Impact Collision Modes for Two Rates of Initial Velocity

impact forces. The craft should not roll significantly as a result of the impact. The time of contact will depend on velocity, initial roll angle, and impact force, but impact times on the order of 1 sec or less may generally be expected for rolled impact.

Figure 41 presents predictions for frame racking as a function of initial roll angle for crush loads of 20- and 50-kip in. impacts with initial velocities of 10 and 20 in./sec. For the initial roll angles investigated (1, 3, 5, and 8 deg) it is concluded that the higher the initial roll angle, the more severe the damage.

Since the initially rolled, off-cushion JEFF will not roll significantly during side collision, frame racking can be expected to occur progressively until either (1) the energy is absorbed by the frames or (2) the machinery deck structure makes contact and absorbs the remainder of the impact energy. When the initial roll angle is high, large frame deformations are possible before main deck contact. An initial roll angle of about 5 deg and an athwartship impact velocity of 10 in./sec are probably to be expected as upper limits on the impact geometry. Under these conditions, it is predicted that a loaded JEFF will experience about 6.5 in. of deflection at the top of the frame if the crush force is 20 kip and about 5.0 in. if the crush force is 50 kip. The crush force is the force necessary to plastically deform the frame and is therefore defined by the impacted structure rather than the impact conditions. This amount of deflection is potentially damaging to critical equipment housed on the machinery deck. Midheight deflections will be approximately 50 percent of the deflections at the top of the frame, resulting in deflections of 3.25 and 2.5 in. where most of the heavy machinery is located. According to the allowable deflection criteria presented earlier (Figure 19), this is likely to be disabling if the impact occurs in the vicinity of the air intakes on either craft, near the propulsors of the JEFF(B) and near the engines of the JEFF(A).

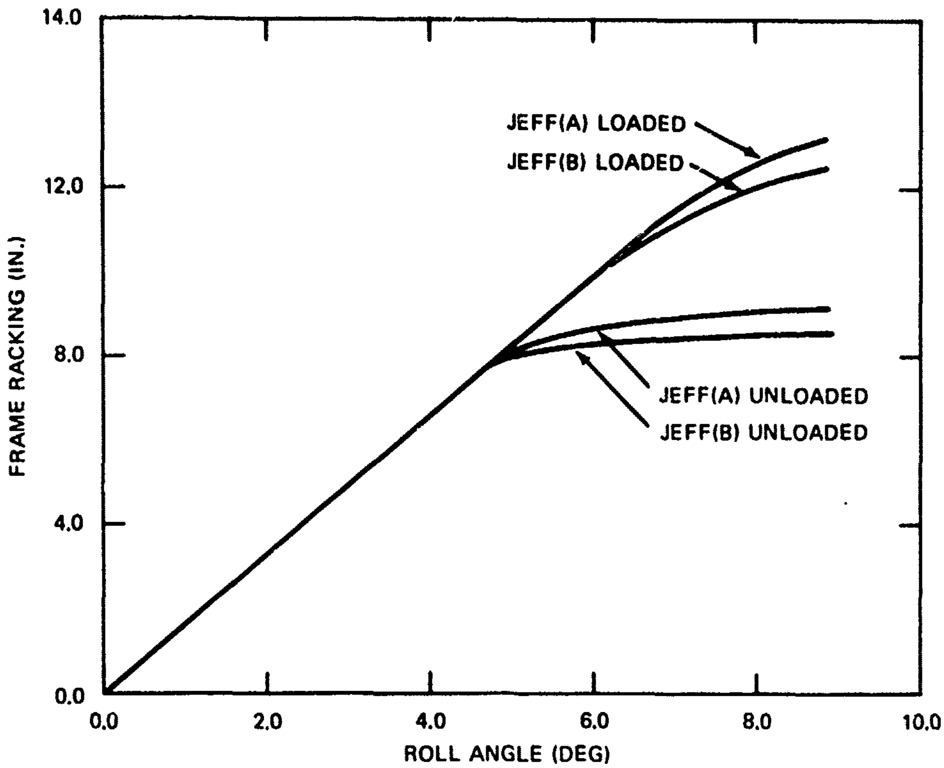
Of course, if the JEFF is on-cushion, rolled impact is not as severe a threat initially since a roll angle of more than 10 deg would be required to contact the top of the frame without also contacting the skirt. If contact occurs in the vicinity of an energy-absorbing bumper, main deck impact will occur very early in the collision and frame racking damage will not be as serious a threat. Off-cushion impacts at locations unprotected by the energy-absorbing bumper will constitute the major hazard from frame racking.

SUMMARY

An analysis of the docking vulnerability of two experimental prototype air cushion landing craft, the JEFF(A) and the JEFF(B), has led to the following basic conclusions:

- Bow collisions will be far more serious than side collisions.
- A JEFF craft will be more vulnerable to docking impact damage when in the loaded condition.

Figure 41 – Frame Racking as a Function of Initial Roll Angle



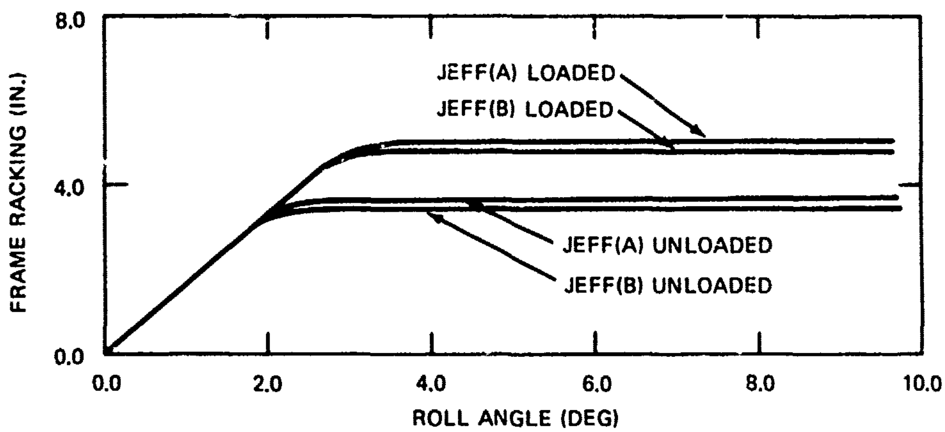
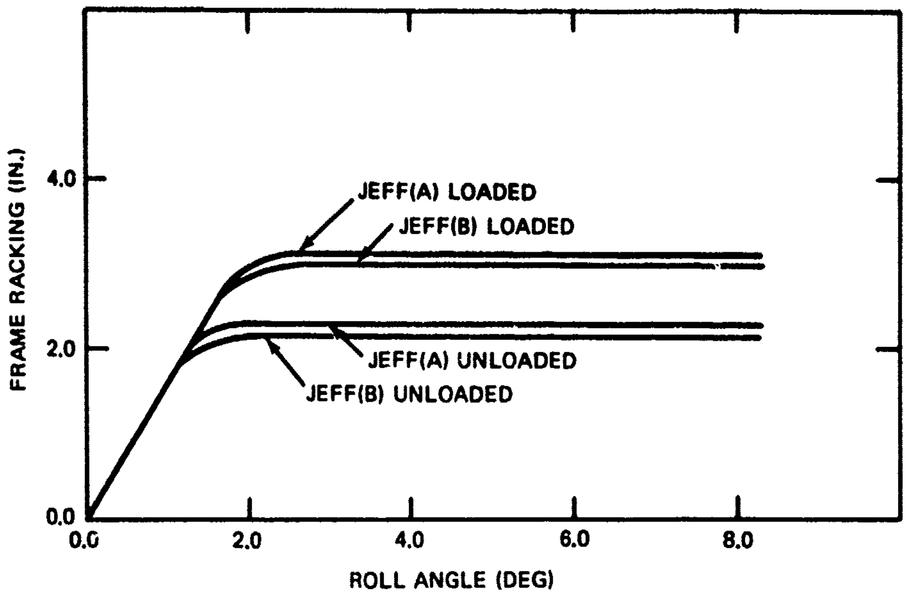


Figure 41a – Crush Load Equals 20 KIPS, Velocity Equals 20 Inches per Second



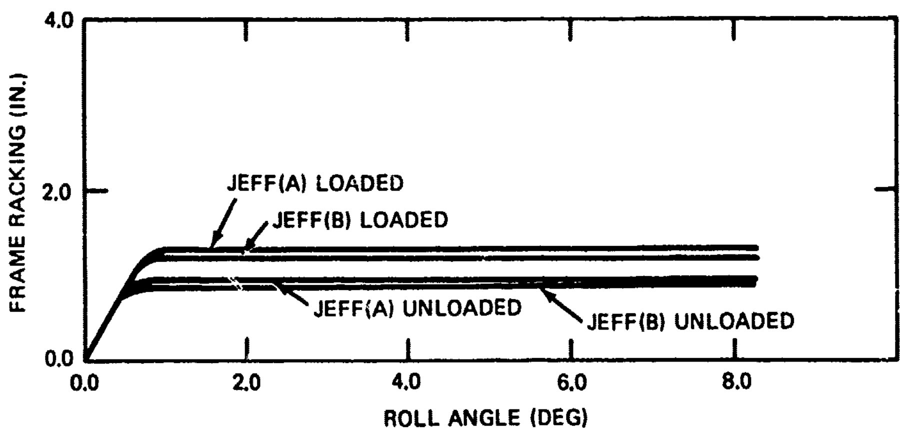


Figure 41b – Crush Load Equals 50 KIPS, Velocity Equals 20 Inches per Second

•A JEFF craft will be much more vulnerable to docking impact damage when off-cushion (displacement mode).

•The farther forward the location of initial impact is, the greater the probability that the hard structure of either JEFF craft in the on-cushion mode will be severely damaged.

•Bow collision impact damage to the JEFF craft will be severe in the absence of suitable fendering at the deck entrance corner of the LPD/LSD transom/well.

•When the craft is on-cushion, the cushion reaction of the pressurized flexible skirt system should generally be sufficient to prevent hard structure contact for side impact at small angles of initial velocity and small relative yaw.

•Craft hard structure deformation will occur for side impacts at large velocity attack angles and large initial yaw angles.

•In general, the JEFF(A) skirt configuration offers greater protection against hard structure contact for on-cushion side collisions than does that of the JEFF(B).

•Off-cushion JEFF craft will be vulnerable to side impacts which result in hard structure deformations since these may seriously affect the lift machinery systems of both craft configurations.

•JEFF craft side impact deformations are likely to increase when the craft is yawed sufficiently to cause the opposite side bow corner to impact the well deck sidewall.

•The bumpers proposed for the JEFF craft do not provide total coverage for the full range of side impact possibilities and do not absorb significant energy in most side collisions.

•Because the off-cushion JEFF craft skirt hinge is very vulnerable to impact damage, it is recommended that a protective rub rail or bumper be provided along the length of the craft.

•The proposed "ferry-slip" LPD/LSD energy-absorbing well deck entrance fendering was not specifically studied, but it is evident that it should significantly reduce bow impact damage. Thus serious consideration should be given to providing this protection.

RECOMMENDATIONS FOR REDUCING CRAFT VULNERABILITY TO COLLISION DURING DOCKING

The relative severity of the various forms of impact studied here enable several general observations to be made concerning the least vulnerable method of docking. These comments apply to both the JEFF(A) and JEFF(B) designs.

Of course, the safest entry is one where there is no contact of the JEFF with the well deck sidewalls, but it is extremely unlikely that this is achievable. The options, then, are limited to reducing the severity of the impact.

Bow collisions are far more serious than side collisions. Either they must be avoided or a specific energy-absorbing structure must be placed either (1) on the craft or (2) on the transom of the LPD/LSD well deck to prevent damage to the JEFF bow structure. The energy-absorbing bumpers on the JEFF are effective, but hard structure damage still results during impacts in the loaded and off-cushion conditions. Repeated impacts could result in serious operational degradation.

Pneumatic fenders are available which have the capability of absorbing the necessary energy to prevent the JEFF from impacting the end wall of the LPD/LSD in a bow collision. Fenders can also be selected to absorb the required energy at load levels low enough to prevent hard structure damage to the bow of the JEFF.

It has been proposed that such fenders be used as energy absorbers behind a flared, hinged wall, thus extending the sidewalls of the well deck to form a "ferry-slip" entrance.[6] This concept appears feasible for absorbing the energy of the bow collisions studied here and may convert borderline bow collisions into side collisions. The concept does not cure all docking collision problems, however; an impact with the flared "ferry-slip" entrance could impart a rotational motion to the craft and possibly result in serious side collisions.

Side collisions are glancing blows and the more shallow the angle of impact, the less severe the damage. Therefore, the better the craft alignment with the well deck on docking, the less severe the docking impact. Also, as the velocity attack angle diminishes, the impact severity decreases. The most significant parameter to impact severity, however, is impact velocity. The damage is related to the square of the velocity, and therefore even small reductions in impact velocity can significantly reduce damage.

Another way to reduce impact damage is to distribute the impact load to more of the craft. This means docking impact at low roll angles inasmuch as the impact energy to be absorbed usually at higher roll angles must be achieved at the top of the transverse framing. Energy absorption is inefficient at that location and significant damage may be expected. When initial on-cushion side collision contact occurs close to the bow, very little cushion contacts the well deck sidewall and the energy absorption is less efficient than when the initial contact point is farther aft. This means that for on-cushion, side collisions, the farther the JEFF can be moved into the well deck before contact occurs, the more air bag is available for energy absorption and therefore the less likelihood of hard structure contact and damage.

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[6] "External Fendering System Arrangement and Details," Norfolk Naval Shipyard Drawings 80064-601-2060804.

When energy-absorbing bumpers make contact with the well deck corner or sidewall, they are quite effective in side collisions of the JEFF. Unfortunately, the current JEFF designs provide for bumpers only at the bow and stern extremities of the side structure, and bumper contact with the well deck is rare in side collisions. An energy-absorbing bumper along the entire side of the craft could provide the JEFF with side collision protection for all cases investigated. The use of partial-length bumpers offers some protection when the bumpers run from the bow aft, but when this partial length starts from a point along the side and runs aft, there is danger that the well deck corner will snag the bumper, particularly in off-cushion side collisions. The motions and damage resulting from such an encounter are potentially severe.

The skirt hinge is a particularly vulnerable part of the JEFF craft, especially in off-cushion docking. A protective rub rail or full-length bumper is recommended to avoid losing large segments of the skirt.

To summarize, then, the ideal docking occurs at a very small relative velocity, at a small velocity attack angle (i.e., no side slip), at small yaw angles, and at small roll angles; moreover, the impact should be a side collision with the initial contact point as far aft on the craft as possible. Craft docking operations are best when the JEFF is on-cushion and unloaded. Although ideal docking conditions cannot always be achieved, the method of docking should be selected in an attempt to meet these conditions.

Several additional factors influence the selection of a docking method. Since both the LPD/LSD and the JEFF are likely to be underway at the time of docking, a wake is present aft of the well deck entrance. This wake may be suppressed to various extents by varying the position of the trailing, submerged well deck sterngate. For a smooth docking the wake should be as small as possible. It may be feasible to alter the locking mechanism of the well deck sterngate to allow adjustments of the door position to minimize the wake. If the craft can gradually approach the well deck entrance rather than negotiate a wake through fluctuating propulsion settings, its docking velocity will be slower and docking collision less hazardous.

An optical alignment system should be used for a straight-in approach to ensure that the bow of the craft is laterally positioned and correctly aligned. This is necessary to avoid bow collisions and to minimize initial yaw of the craft relative to the well deck centerline. The proposed ferry-slip entrance will reduce the need for accurate lateral positioning, but it will certainly not eliminate the need for the optical alignment system.

Another docking method may be considered if the ferry-slip entrance modification is made, namely, bringing the JEFF alongside the flared ferry-slip side and then following the side into the well deck. This method of docking appears to violate many of the ideal docking conditions. For example, initial yaw angle is high, initial velocity attack angle is high, and the initial contact point is far forward on the JEFF. Nevertheless, the approach is worth considering because the initial impact is distributed over a larger area by the flared side of the ferry-slip entrance and the craft is cushioned by the energy-absorbing fender in the mechanism. The relative velocities following the initial impact are quite small as the JEFF "follows" the sidewall into the well deck. Impact velocity is so significant a factor in damage that impact geometry considerations may be waived if the impact velocity can be significantly reduced. This docking method may be feasible if the wake and the flow past the sides of the LPD/LSD do not act adversely on the yawed JEFF near the time of initial contact with the ferry-slip side.

In summary, two possible docking methods appear feasible. The more attractive, especially if the wake aft of the LPD/LSD can be adequately suppressed, seems to be straight-in-docking with optical alignment aids and with ferry-slip modifications to the well deck entrance to ensure against bow impacts. Not quite as attractive perhaps but still a potentially feasible docking method is for the JEFF to come alongside the ferry-slip flared sidewall and follow it into the well deck.

ACKNOWLEDGMENTS

Harry Hashmall and Robert Gorman of NSRDC conducted the computer runs for the JEFF analysis. Raymond Allen of NSRDC assisted in defining the program and John Offutt and Martin Fink of the AALC Program Office at NSRDC supplied important information and guidance.

APPENDIX A

USER'S MANUAL FOR COMPUTER PROGRAM DOCK

INTRODUCTION

Computer program DOCK was written to solve the interaction problems of energy absorption and rigid body motions in the horizontal plane for the docking collision which occurs when the JEFF craft enters the well deck of an LSD or LPD.

The computer program is written in FORTRAN IV for use with the CDC-6700 computer operating at NSRDC under the Scope 3.3 control system. The input data for DOCK are in the form of cards punched on the IBM-26 card punch. Specifications for the preparation of the input data and a brief description of the output from the program are included here.

PREPARATION OF DATA

The data must be prepared according to the appropriate formats for successful execution: 21 data blocks ("cards") are the maximum necessary to describe a problem. If certain options are not exercised, then some data are omitted and fewer blocks are necessary. The set of data blocks which completely define the problem is termed a data set. The program is set up to allow the solution of one or more problems and therefore any number of data sets may be input consecutively.

The following is a list of the data blocks ("cards") and the input specifications. Note that much of the option selection data is in the form of word input (alphanumeric characters). These data must be left-adjusted on the data card and the wording must be identical to the wording specified.

CARD 1 – FORMAT(8A10)

BTITLE	An identification title used on all printed output.

CARD 2 – FORMAT(A10)

TYPE	Defines the type of collision The options available are: A) BOW COLLISION B) SIDE COLLISION

CARD 3 – FORMAT(A10,20X,5F10.3)

SLIDE — Defines the option selected for determining the sliding behavior at the collision point.

The following options are available:

A) NO SLIDING – Collision point is constrained and cannot be displaced laterally.

B) LATERAL LOAD DEFINED – Sliding is allowed and the lateral load is defined as a function of lateral deflection on Card 20.

C) SLIDING COLLISION – Sliding is allowed. The lateral load is defined by a coefficient of friction defined later on this card.

D) SLIDING WITH LOAD COMPENSATION – Sliding of the impact point is allowed and lateral loads are defined by a coefficient of friction. The normal crush loads are modified for their proximity to frames.

XMU — The coefficient of sliding friction. Must be specified for SLIDE Options (C) and (D). Otherwise it may be left blank.

The following data are specified only if Option D (load compensation) is selected on Card 3. Otherwise, these variables may be omitted.

FRAMSP — Distance between frames (in).

FRAM — The load (lb) which will cause plastic frame deformation when impact occurs at the frame.

STFF — The distance from the initial location of the collision point to the first frame aft (for a side collision) or the first frame to port (for a bow collision) (in).

DEFS — The crush displacement (in) at which the load modification under Option (D) begins. This variable allows selective application of the load modification option when, for example, it is desirable to delay modification of the impact loading until the cushion is totally crushed and hard structure contact occurs.

CARD 4 – FORMAT(A10)

FLY — Defines whether multiple impacts and free flight are allowed or whether only a single impact is allowed. The options are:

A) MULTIPLE IMPACT

B) SINGLE IMPACT

CARD 5 – FORMAT(6E12.6)

XM	Translational mass (lb-sec^2/in).
XIC	Rotational inertia (lb-sec^2-in) of the craft at the center of gravity.
B	Distance from the center of gravity to the collision point in the longitudinal direction (in).
E	Distance from the center of gravity to the collision point in the athwartship direction (in). If a bow collision is specified, the point of collision cannot be at the craft longitudinal centerline, and therefore E cannot equal zero.

CARD 6 – FORMAT(6F12.6)

WDW	Well deck width of LPD/LSD (in).
CRL	Craft length (in).
CW	Craft width (in).
CGB	Distance from bow to center of gravity of craft (in).
CGP	Distance from portside to center of gravity of craft (in).
XMUC	Coefficient of friction at the opposite corner. This term may be omitted if opposite corner collision is not investigated.

CARD 7 – FORMAT(A10)

COLD	Defines whether opposite corner collision is investigated. The options are: A) CONTACT OPPOSITE SIDE B) NO CONTACT

CARD 8 – FORMAT(2F12.3,I12)

This card is omitted if Option (B) is selected on Card 7.

FØ(K)	Opposite corner crush force at displacement (K) (lb).
DØ(K)	Displacement corresponding to the crush force FØ(K) (in).
ND	A flag to indicate that all points on the load-deflection curve for the opposite corner have been defined. ND = 0 or blank specifies that more data points follow. ND = 1 specifies that no additional data points follow.

Card 8 is actually a set of cards (the maximum is 20). A card is required to define each data point on the load-deflection curve. The cards are arranged in order of increasing deflection and the last card is flagged with ND = 1.

CARD 9 – FORMAT(A10)

This card is omitted if Option (B) is selected on Card 7.

REBO — Defines whether rebound on the opposite corner is investigated. The options are:

A) REBOUND OF OPPOSITE SIDE – This option allows the load deflection function to be applied as the opposite corner unloads.

B) NO REBOUND – This option specifies that the load drops to zero in the unloading situation.

CARD 10 – FORMAT(A10)

TIE — This card indicates whether AID craft-handling system forces are included in the investigation.
The options are:

A) CABLE TOW SYSTEM MODELED

B) CABLE SYSTEM NOT MODELED

CARD 11 – FORMAT(6F12.6)

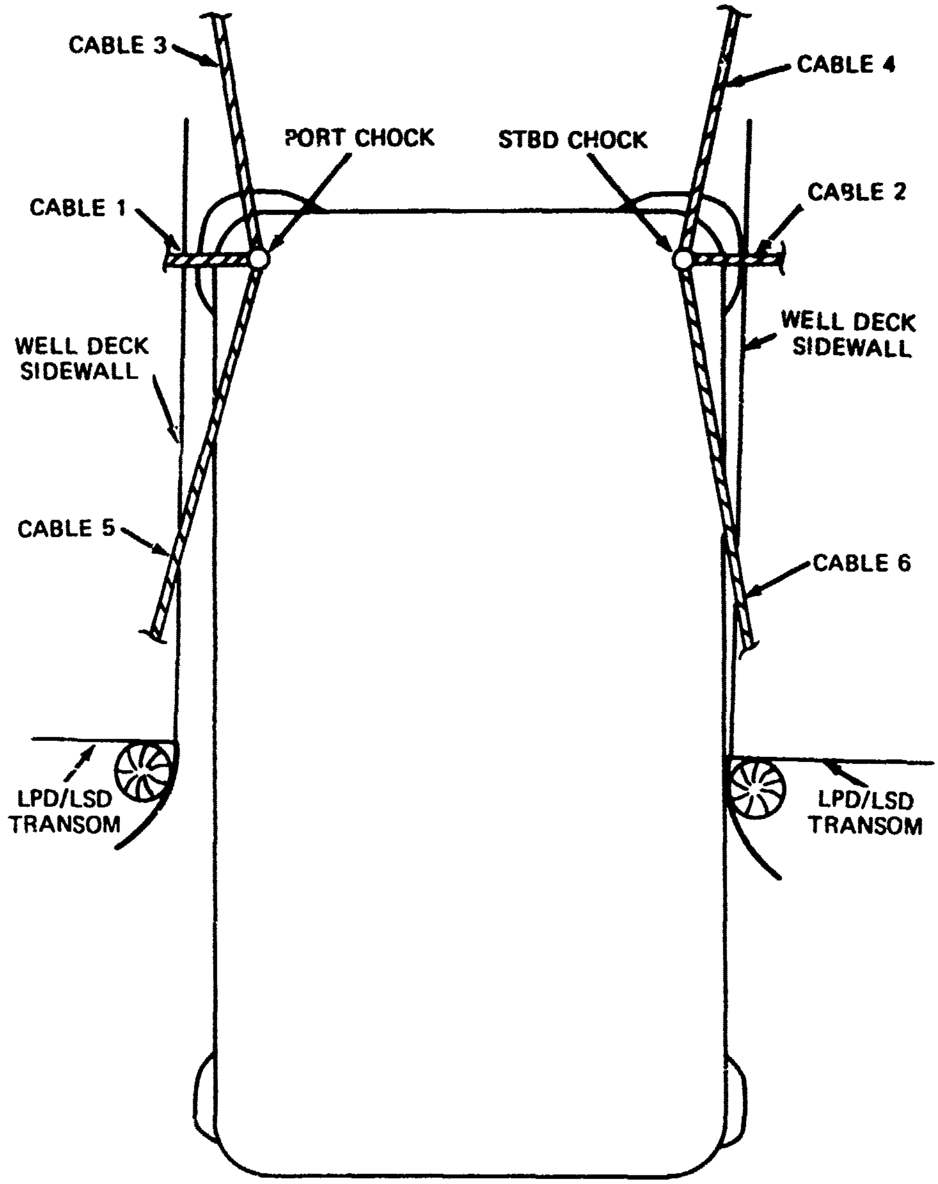
This data block is omitted if Option (B) is selected on Card 10.

PCLAT	Athwartship distance from the craft center of gravity to the port chock (in).
PCLON	Longitudinal distance from the craft center of gravity to the port chock (in).
SCLAT	Athwartship distance from the craft center of gravity to the starboard chock (in).
SCLON	Longitudinal distance from the craft center of gravity to the starboard chock (in).
TCHGT	Vertical distance (in) from the chocks to the tow-in rail of the AID system.

CARD 12 – FORMAT(6F12.6)

This card is omitted if Option (B) is selected on Card 10.

PL(I) — Preload in cable (I) (lb). Each of the preloads is specified in the order of the cable numbers. Cable numbers are indicated in Figure A.1.



CABLE 1 – PORT STABILIZATION (RESTRAINING LINE)
CABLE 2 – STBD STABILIZATION (RESTRAINING LINE)
CABLE 3 – PORT TOW (TOW LINE)
CABLE 4 – STBD TOW (TOW LINE)
CABLE 5 – PORT BRAKE (BRAKING LINE)
CABLE 6 – STBD BRAKE (BRAKING LINE)

Figure A.1 – Definition of Lines in the AID Craft-Handling System

CARD 13 – FORMAT(6F12.6)

This card is omitted if Card 10 selects Option (B).

CLO(I)	Initial cable length of Cable (I) (in). Each of the cable lengths is specified in the order of the cable numbers. Cable numbers are indicated in Figure A.1.

CARD 14 – FORMAT(6E12.6)

Card 14 is omitted if Option (B) is selected on Card 10. This card defines load-deflection information for the cables of the tow-in system. Further definition of the load-deflection parameters is found in Figure A.2.

ETIE	Initial slope of the load-strain curve for the tow cables (lb).
PLTIE	Plastic limit load for the two cables (lb).
ELONG	Elongation strain limit for the cable (breaking point of the cable) (in/in).
PLFAL	Load limit of the towing device on the LPD/LSD (lb).

CARD 15 – FORMAT(A10,20X,5F10.3)

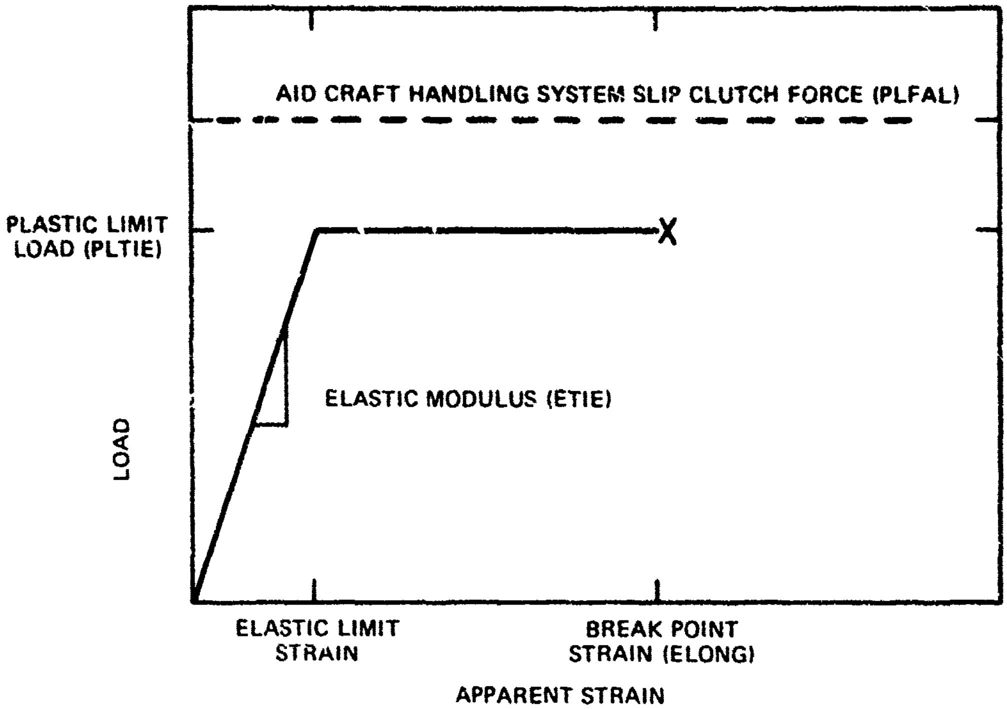
BUMPER	This variable indicates whether a side collision energy-absorbing bumper is modeled. The options are: A) BUMPER DEFINED B) BUMPER NOT DEFINED

If Option (A) is selected, the following data must be defined:

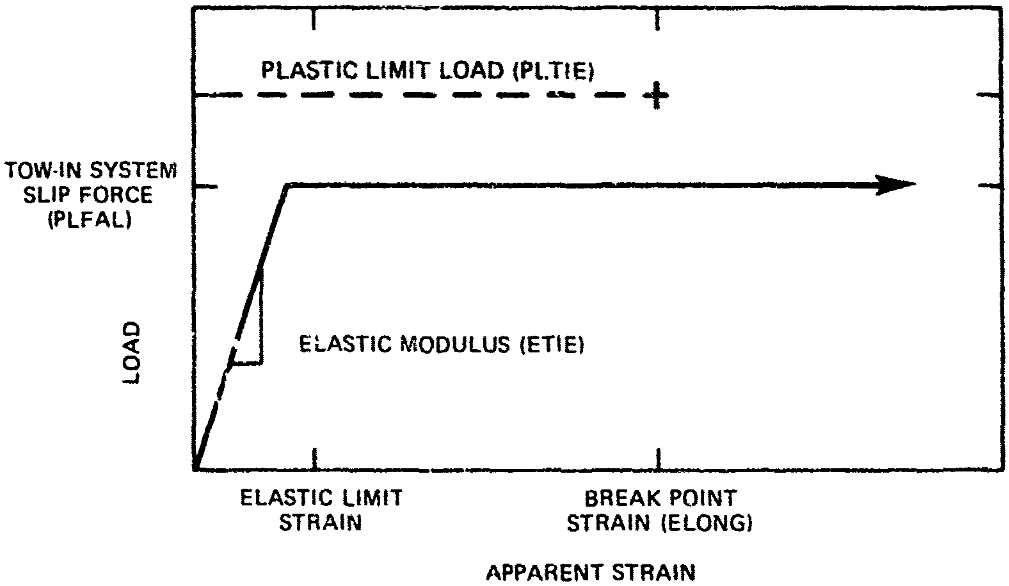
BDEPTH	The bumper depth (in).
BLOC	The distance (in) between the center of gravity and the point of application of the bumper force.
CUSHO	The distance (in) the cushion protrudes beyond the hard structure.
XMUB	Coefficient of friction of the bumper.

CARD 16 – FORMAT(2F12.3,I12)

FB(K)	The crush force (lb) of the bumper at displacement (K).
BD(K)	The displacement (in) of the bumper corresponding to the crush force FB(K).
ND	A flag to indicate that all points on the bumper load-deflection curve have been described. ND = 0 or blank indicates that more data points follow. ND = 1 indicates that no additional data points follow.



CASE A: SLIP CLUTCH FORCE GREATER THAN PLASTIC LOAD LIMIT



CASE B: SLIP CLUTCH FORCE LESS THAN PLASTIC LOAD LIMIT

Figure A.2 – Typical Cable Force Functions of AID Craft-Handling System

Card 16 is actually a set of cards (maximum of 20). A card is necessary to describe each point on the load-deflection curve. The cards are arranged in order of increasing deflection, and the last card is flagged with ND = 1. If Option (B) is selected on Card 15, Card 16 is omitted.

CARD 17 – FORMAT(6F12.6)

VZ	Translational velocity (in/sec) at the time of the collision.
PHI	Attack angle (deg) of the collision velocity (VZ) clockwise from the well deck centerline.
THZ	Yaw angle (deg) of the craft relative to the well deck centerline at the time of collision.
OMGZ	Initial rotational velocity (deg/sec) of the craft relative to the well deck (clockwise position).

CARD 18 – FORMAT(6F12.6)

TMAX	Maximum time (sec) to which the solution is to be carried.
DT	Time increment (sec) for calculations.
DTP	Time increment (sec) for output. DTP should be an integer multiple of DT. The number of time increments is limited to 999, and therefore TMAX/DT must be less than or equal to 999.

CARD 19 – FORMAT(2F12.3,I12)

F(I)	The crush force (lb) at the point of collision at displacement (I) in the direction normal to the surface of the craft.
D(I)	The displacement (lb) corresponding to the crush force F(I).
ND	A flag to indicate that all points on the load deflection curve have been described. ND = 0 or blank indicates that more data points follow. ND = 1 indicates that no additional data points follow.

Card 19 is actually a set of cards (maximum of 20). A single card is necessary to define each point on the load-deflection curve. The cards are arranged in order of increasing displacement and the last card is flagged with ND = 1.

CARD 20 – FORMAT(2F12.2,I12)

This card is used only if Option (B) is selected on Card 3. Otherwise the card is omitted.

FL(I)	The force (lb) in the lateral direction at lateral deflection (I).
DL(I)	The lateral deflection (in) corresponding to the lateral force FL(I).
ND	A flag to indicate that all data points of the lateral load-deflection curve are defined. ND = 0 or blank indicates that additional data points follow. ND = 1 indicates that no additional data points follow.

Card 20 is actually a set of cards (maximum of 20). A card is necessary to define each data point on the load-deflection curve. The cards are arranged in order of increasing deflection and the last card is flagged with ND = 1.

CARD 21 – FORMAT(8A10)

BTITLE	If another data set follows, this is actually Card 1 of the next data set and describes the title to be used for the next problem. If the data defined immediately prior to this card is the last data set to be solved in the computer run, the card must read: END OF SUBMITTED DATA

Additional problems are solved by simply repeating Cards 1 through 21 for additional problems.

Figure A.3 is a listing of a set of data cards defining two sample data sets. Note that the option for investigating opposite corner collision is not selected for the first case, but is included for the second case. This means that card block numbers 8 and 9 are omitted in the first data set and not in the second. The cable tow-in system option is selected in the first data set but not in the second; therefore, the data blocks associated with the cable tow-in option (card blocks 11–14) are omitted, in the second data set. In the first data set card block 16 is not included because the energy-absorbing bumper is not modeled and card block 20 is not included because a load-deflection function is not used to define lateral loads at the collision point.

```
SAMPLE INPUT DATA SET ONE
SIDE COLLISION
SLIDING WITH LOAD COMPENSATION 0.3      24.0      35000.0   12.0      25.6
SINGLE IMPACT
0.9099E   03 0.1275 E 09 0.4809 E 03  0.2019E 03
   576.0        1153.6      574.2     542.2       287.1
NO CONTACT
CABLE TOW SYSTEM MODELED
282.5       450.        282.5       450.        150.
100.        100.        200.        200.        0.          0.
200.        200.        800.        800.        550.        550.
1.5  E      6 1.5 E     4 0.35 E    0 1.0 E      4
BUMPER NOT DEFINED
  60.0        35.0         -1.0        0.0
   20.0       .025        0.025
     0.0      0.0
  2079.6      15.0
 52148.92    15.5
  52911.44   21.0
  53466.00   25.0
70000.       25.1              1
SAMPLE INPUT DATA SET TWO
SIDE COLLISION
LATERAL LOAD DEFINED
MULTIPLE IMPACT OPTION
0.9099E   03 0.1275 E 09 0.4809 E 03  0.2019E 03
   576.      960.       516.       491.9       268.      .3
CONTACT OPPOSITE SIDE
0.0         0.0
50000.      0.5
50800.      8.0
135000.     10.                1
NO REBOUND
CABLE SYSTEM NOT MODELED
BUMPER DEFINED                 10.0       535.      10.0   0.0
0.0         0.0
50000.      0.5
50000.      8.0
135000.     10.                1
  60.0        35.0         -1.0        0.0
   20.0       .025        0.025
     0.0      0.0
  2079.6      15.0
 52148.92    15.5
  52911.44   21.0
  53466.00   25.0
70000.       25.1              1
0.0         0.0
5000.       10.
20000.      30.
20000.      50.       1
END OF SUBMITTED DATA
```

Figure A.3 – Listing of Sample Input Data Cards

DESCRIPTION OF OUTPUT

All output from DOCK is printed output. The output is controlled to some extent by the options selected in the input data.

The printed output from DOCK is titled by the title specified on Card 1 of the input data and includes the following:

1. A statement of the input data concerning craft size and displacement, collision geometry and velocities, and a table defining the load-deflection functions for each of the fuctions defined in the input. If the energy-absorbing bumper is defined, that definition is also specified.

2. A statement of the sign convention used in DOCK and in which the response data are presented.

3. A time history of craft motions at the point of contact with the well deck corner. This time history is in the craft coordinate system and includes longitudinal and athwartship displacements and velocities. The craft coordinate system is aligned with the craft centerline and moves with the craft as it enters the well deck. Also included in this listing is a definition of the collision point forces.

4. A summary statement of the final collision point positions, the maximum deflection of the opposite corner and the associated energy absorption, and the maximum deflection of the energy-absorbing bumper and associated energy absorption. Of course, if options investigating bumper and opposite corner impact are not selected, portions of this summary are not output.

5. A time history of craft motions at the point of collision in the ground coordinate system. Also printed here is the energy absorbed at the point of collision in the directions normal to and parallel with the surface of the craft.

6. A time history of the craft motions at the center of gravity of the craft in the ground coordinate system. This coordinate system is oriented with the well-deck centerline and does not move relative to the well deck.

7. A time history of the kinetic energies associated with the craft center of gravity and a statement of the total kinetic energy and the net kinetic energy loss.

8. When opposite side collisions are investigated, a time history of the response at the opposite bow corner is listed. Crush deflections, associated forces, and absorbed energies are listed at each printout time increment.

9. When the effect of the energy-absorbing bumper is investigated, a time history of the bumper response is listed. Bumper deformation, associated forces, and absorbed energies are listed at each printout time increment.

10. When the effect of the AID craft-handling system is investigated, a time history of the cable forces and associated energy absorption is listed for each of the six tow-in cables.

All time histories are listed at the time increment defined in the input data. If the printout time increment is not an integer multiple of the calculation time increment, then the printout increment is reduced to the highest integer multiple of the calculation time increment which is less than the specified printout increment. The time is printed in all time histories.

APPENDIX B

DOCK PROGRAM LISTING

```
      PROGRAM DOCK(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                DOCK
      DIMENSION X(3,1000),V(3,1000),XB(2,1000),VB(2,1000),BTITLE(8),F(20 DOCK
     1),D(20),ECFR(1000),ECCP(1000),FL(20),DL(20)                        DOCK
      DIMENSION FO(20),DO(20)                                            DOCK
      DIMENSION DD(1000,5)                                               DOCK
      DIMENSION CL(6,1000),CF(6,1000),CLM(6),CLO(6),STR(6),PL(6),EP(3,10 DOCK
     1000),ES(3,1000)                                                    DOCK
      DIMENSION FB(20),BD(20)                                            DOCK
      DIMENSION ZBF(1000),ZBFL(1000),ZBE(1000),ZBX(1000),ZBEL(1000)      DOCK
      DATA BUMPT/10HBUMPER DEF/                                          DOCK
      DATA TIET/10HCABLE TOW /                                           DOCK
      DATA COLDT/10HCONTACT OP/                                          DOCK
      DATA REBOT/10HREBOUND OF/                                          DOCK
      DATA SLIDS/10HLATERAL LO/                                          DOCK
      DATA SLIDT/10HSLIDING CO/                                          DOCK
      DATA SLIDF/10HSLIDING WI/                                          DOCK
      DATA BOWT/10HBOW COLLIS/                                           DOCK
      DATA ENDT/10HEND OF SUB/                                           DOCK
      DATA FLYT/10HMULTIPLE I/                                           DOCK
  710 CONTINUE                                                           DOCK
      NSLIDE=0                                                           DOCK
      IFLAG=0                                                            DOCK
      NBOW=0                                                             DOCK
      READ(5,1) (BTITLE(I),I=1,8)                                        DOCK
    1 FORMAT (8A10)                                                      DOCK
      IF (BTITLE(1).EQ.ENDT) GO TO 999                                   DOCK
      READ (5,4) TYPE                                                    DOCK
    4 FORMAT (A10)                                                       DOCK
      READ (5,40) SLIDE,XMU,FRAMSP,FRAM,STFF,DEFS                        DOCK
   40 FORMAT (A10,20X,5F10.3)                                            DOCK
      IF (SLIDE.EQ.SLIDT) NSLIDE=1                                       DOCK
      IF (SLIDE.EQ.SLIDS) NSLIDE=-1                                      DOCK
      IF (SLIDE.EQ.SLIDF) NSLIDE=2                                       DOCK
      IF (TYPE.EQ.BOWT) NBOW=1                                           DOCK
      NFLY=0                                                             DOCK
      READ (5,4) FLY                                                     DOCK
      IF (FLY.EQ.FLYT) NFLY=1                                            DOCK
      READ (5,2) XM,XIC,R,E                                              DOCK
```

```
      BB=B                                                              DOCK  40
      EE=E                                                              DOCK  41
    2 FORMAT (6E12.6)                                                   DOCK  42
    3 FORMAT (6F12.6)                                                   DOCK  43
      NCON=0                                                            DOCK  44
      READ (5,3) WOW,CRL,CW,CGB,CGP,XMUC                                DOCK  45
      READ (5,4) COLD                                                   DOCK  46
      IF (COLD.EQ COLDT) NCON=1                                         DOCK  47
      CGS=CW-CGP                                                        DOCK  48
      IF (NCON.LE  ) GO TO 296                                          DOCK  49
      DSWLST=0.0                                                        DOCK  50
      YBOCST=0.0                                                        DOCK  51
      YBOC=0.0                                                          DOCK  52
      XMOC=0.0                                                          DOCK  53
      XMOCR=0.0                                                         DOCK  54
      TOC=0.0                                                           DOCK  55
      DO 891 L=1,5                                                      DOCK  56
  891 DD(1,L)=0.0                                                       DOCK  57
  808 CONTINUE                                                          DOCK  58
      NO=0                                                              DOCK  59
      DO 865 K=1,20                                                     DOCK  60
      NO=NO+1                                                           DOCK  61
      READ (5,200) FO(K),DO(K),ND                                       DOCK  62
      IF (ND.GT.0) GO TO 866                                            DOCK  63
  865 CONTINUE                                                          DOCK  64
  866 FO(21)=FO(NO)                                                     DOCK  65
      NREBO=0                                                           DOCK  66
      READ(5,4) REBO                                                    DOCK  67
      IF(REBO.EQ.REBOT) NREBO=1                                         DOCK  68
  296 CONTINUE                                                          DOCK  69
      NTIE=0                                                            DOCK  70
      READ (5,4) TIE                                                    DOCK  71
      IF (TIE.EQ.TIET) NTIE=1                                           DOCK  72
      IF (NTIE.LE.0) GO TO 294                                          DOCK  73
      READ (5,3) PCLAT,PCLON,SCLAT,SCLON,TCHGT                          DOCK  74
      READ (5,3) (PL(I),I=1,6)                                          DOCK  75
      READ (5,3) (CLO(I),I=1,6)                                         DOCK  76
      READ (5,2) ETIE,PLTIE,ELONG,PLFAL                                 DOCK  77
```

```
      STRF=PLFAL/ETIE                                                   DOCK
      STRP=PLTIE/ETIE                                                   DOCK
      CLOT5=SQRT(CLO(5)*CLO(5)-TCH2)                                    DOCK
      CLOT6=SQRT(CLO(5)*CLO(6)-TCH2)                                    DOCK
      KFLG1=0                                                           DOCK
      KFLG2=0                                                           DOCK
      KFLG3=0                                                           DOCK
      KFLG4=0                                                           DOCK
      KFLG5=0                                                           DOCK
      KFLG6=0                                                           DOCK
      DTH=0.0                                                           DOCK
      TCH2=TCHGT*TCHGT                                                  DOCK
      YPCA=0.0                                                          DOCK
      YPCF=0.0                                                          DOCK
      YSCA=0.0                                                          DOCK
      YSCF=0.0                                                          DOCK
      DO 291 J=1,3                                                      DOCK
      EP(J,1)=0.0                                                       DOCK
  291 ES(J,1)=0.0                                                       DOCK
      DO 230 J=1,6                                                      DOCK
      CLM(J)=CLO(J)                                                     DOCK
      CL(J,1)=CLO(J)                                                    DOCK
      CF(J,1)=0.0                                                       DOCK
  230 STR(J)=PL(J)/ETIE                                                 DOCK
  204 CONTINUE                                                          DOCK
      READ(5,40) BUMPER,BDEPTH,BLOC,CUSHO,XMJB                          DOCK
      BLAT=CGS+BDEPTH-CUSHO                                             DOCK
      NBUMP=0                                                           DOCK
      IF(BUMPER.EQ.BUMPT) NBUMP=1                                       DOCK
      IF(NBUMP.LE.0) GO TO 38                                           DOCK
      EBUMP=0.0                                                         DOCK
      EBUMPT=0.0                                                        DOCK
      BCRMX=0.0                                                         DOCK
      BPYLST=0.0                                                        DOCK
      BPXLST=0.0                                                        DOCK
      NBU=0                                                             DOCK
      DO 39 K=1,20                                                      DOCK
      NBU=NBU+1                                                         DOCK
```

```
      READ(5,200) FB(K),BD(K),ND                                         DOCK
      IF(ND.GT.0) GO TO 41                                               DOCK
   39 CONTINUE                                                           DOCK
   41 FB(21)=FB(NBU)                                                     DOCK
   38 CONTINUE                                                           DOCK
      READ (5,3) VZ,PHI,THZ,OMGZ                                         DOCK
      READ (5,3) TMAX,DT,DTP                                             DOCK
      X(1,1)=0.                                                          DOCK
      X(2,1)=0.                                                          DOCK
      X(3,1)=THZ/57.296                                                  DOCK
      PHI=PHI/57.296                                                     DOCK
      V(1,1)=VZ*SIN(PHI)                                                 DOCK
      V(2,1)=VZ*COS(PHI)                                                 DOCK
      V(3,1)=OMGZ/57.296                                                 DOCK
      VOBYS=V(2,1)+V(3,1)*CGS                                            DOCK
      VOLAT=V(1,1)+V(3,1)*CGB                                            DOCK
      PHI=PHI*57.296                                                     DOCK
      T=0.0                                                              DOCK
      NP=1                                                               DOCK
      FT=0.                                                              DOCK
      ALPA=ATAN(B/E)                                                     DOCK
      CALP=COS(ALPA)                                                     DOCK
      ZETA=ALPA-X(3,1)                                                   DOCK
      R=SQRT(B*B+E*E)                                                    DOCK
      XB(1,1)=0.                                                         DOCK
      XB(2,1)=0.                                                         DOCK
      VB(1,1)=V(1,1)+V(3,1)*R*SIN(ZETA)                                  DOCK
      VB(2,1)=V(2,1)-V(3,1)*R*COS(ZETA)                                  DOCK
      XBC=XB(1,1)*COS(X(3,1))-XB(2,1)*SIN(X(3,1))                        DOCK
      YBC=XB(1,1)*SIN(X(3,1))+XB(2,1)*COS(X(3,1))                        DOCK
      VYC=V(2,1)*COS(X(3,1))+V(1,1)*SIN(X(3,1))                          DOCK
      VXC=-V(2,1)*SIN(X(3,1))+V(1,1)*COS(X(3,1))                         DOCK
      VBXC=V(3,1)*R*SIN(ALPA)+VXC                                        DOCK
      VBYC=V(3,1)*R*COS(ALPA)+VYC                                        DOCK
      NF=0                                                               DOCK
      DO 65 I=1,20                                                       DOCK
      NF=NF+1                                                            DOCK
      READ (5,200) F(I),D(I),ND                                          DOCK
```

```
200 FORMAT (2F12.3,I12)                                                      DOCK
    IF (ND.GT.0) GO TO 201                                                   DOCK
 65 CONTINUE                                                                 DOCK
201 CONTINUE                                                                 DOCK
    F(20)=F(NF)                                                              DOCK
    FC=F(1)                                                                  DOCK
    IF (ISLIDE.GE.0) GO TO 15                                                DOCK
    NL=0                                                                     DOCK
    DO 11 I=1,20                                                             DOCK
    NL=NL+1                                                                  DOCK
    READ (5,200) FL(I),DL(I),ND                                              DOCK
    IF (ND.GT.0) GO TO 16                                                    DOCK
 11 CONTINUE                                                                 DOCK
 16 FL(20)=FL(NL)                                                            DOCK
 15 NPTS=TMAX/DT+1.0001                                                      DOCK
    NPT=DTP/DT+0.0001                                                        DOCK
    IF (NPTS.LE.1000) GO TO 998                                              DOCK
    WRITE (6,997)                                                            DOCK
997 FORMAT (///1X,*TMAX AND DT NOT CONSISTANT WITH DIMENSION*)               DOCK
    GO TO 999                                                                DOCK
998 CONTINUE                                                                 DOCK
    WRITE (6,100) (TITLE(I),I=1,8),XM,XIC,B,E                                DOCK
100 FORMAT (1H1,10X,*AALC DOCKING COLLISION PROGRAM*//1X,8A10///5X,*IN       DOCK
   1PUT DATA - CRAFT PROPERTIES (LB-IN-SEC UNITS)*//1X,*TRANSLATIONAL        DOCK
   2INERTIA *,E12.6/1X,*ROTATIONAL INERTIA *,E12.6/1X,*DISTANCE FROM C       DOCK
   2G TO COLLISION POINT (Y-CRAFT DIRECTION) *,F12.3/1X,*DISTANCE FROM       DOCK
   3 CG TO COLLISION POINT (X-CRAFT DIRECTION) *,F12.3)                      DOCK
    YBCLST=0.                                                                DOCK
    FCLAST=0.0                                                               DOCK
    XKE=XM*VZ*VZ/2.+XIC*V(3,1)*V(3,1)/2.                                     DOCK
    IF (IBOW.EQ.1) GO TO 72                                                  DOCK
    WRITE (6,555)                                                            DOCK
    GO TO 73                                                                 DOCK
 72 WRITE (6,556)                                                            DOCK
 73 CONTINUE                                                                 DOCK
    IF (IFLY.LE.0) GO TO 79                                                  DOCK
    WRITE (6,98)                                                             DOCK
 98 FORMAT (//* MULTIPLE IMPACT WITH FREE FLIGHT INVESTIGATED*/)             DOCK
```

```
      GO TO 99
   79 WRITE (6,106)
  106 FORMAT (//* SINGLE IMPACT INVESTIGATED*/)
   99 CONTINUE
  555 FORMAT (//1X,*THIS IS A SIDE COLLISION*)
  556 FORMAT (//1X,*THIS IS A BOW COLLISION*)
      IF (NCON.LE.0) GO TO 820
      WRITE (6,2050) WDW,CRL,CW,CGB,CGP,XMUC
      WRITE (6,2051) (DD(K),FD(K),K=1,ND)
 2050 FORMAT (///1X,*OPPOSITE CORNER CONTACT INVESTIGATED*/10X,*WELL DEC
     1K WIDTH (IN) = *,F10.3/10X,*CRAFT LENGTH (IN) = *,F10.3/10X,*CRAFT
     2 WIDTH (IN) =*,F11.3/10X,*CG TO BOW DISTANCE (IN) = *,F10.3/10X,*C
     3G TO PORT DISTANCE (IN) = *,F10.3/10X,*FRICTION COEFFICIENT = *,F1
     40.3/)
 2051 FORMAT (/1X,*LOAD-DEFLECTION CURVE FOR OPPOSITE CORNER (LB-IN UNIT
     1S)*//2X,*DEFLECTION*,6X,*LOAD*//(2E16.5))
      CPB=CGB-3
      TESW=CW*COS(X(3,1))-CPB*SIN(X(3,1))
      DSW=TESW-WDW
      IF (DSW.GT.0.0) DSWLST=DSW
      DD(1,1)=DSWLST
      IF (NREBO.LE.0) GO TO 823
      WRITE (6,824)
  824 FORMAT (//* ELASTIC REBOUND OF OPPOSITE CORNER PERMITTED*//)
      GO TO 821
  823 WRITE (6,825)
  825 FORMAT (//* IMPACT ON OPPOSITE CORNER IS DEFINED AS PLASTIC*/)
      GO TO 821
  820 WRITE (6,822)
  821 CONTINUE
  822 FORMAT (///,1X,*OPPOSITE CORNER CONTACT NOT INVESTIGATED*/)
      WRITE (6,101) VZ,PHI,THZ,XKE
  101 FORMAT (/////5X,*COLLISION GEOMETRY (IN-SEC-DEGREE UNITS)*//1X,*VE
     1LOCITY VECTOR *,E12.6/1X,*VELOCITY ATTACK ANGLE (GROUND REFERENCE)
     2 *,E14.6/1X,*INITIAL YAW ANGLE (GROUND REFERENCE) *,E14.6/1X,*INIT
     3IAL KINETIC ENERGY (IN-LBS) *,E12.6///)
      IF (NSLIDE.GE.1) GO TO 70
      IF (NSLIDE.EQ.0) GO TO 14
```

```
      WRITE (6,553)
  553 FORMAT (//1X,*THIS IS A SLIDING COLLISION WITH LATERAL LOAD DEFINI
     1TION*)
      GO TO 71
 1138 CONTINUE
      XSTIF=STFF
      DAF=STFF
      DFF=FRAMSP-DAF
      IF (DFF.LT.DAF) XSTIF=DFF
      IF (IBOW.GT.0) GO TO 138
      WRITE (6,136) FRAMSP,FRAM,STFF,DEFS
  136 FORMAT (///1X,*THE CRUSH FORCES ARE MODIFIED BY THE PROXIMITY TO F
     1RAMES*/5X,*FRAME SPACING (IN) = *,F10.3/5X,*FRAME CRUSH FORCE (LB)
     2 = *,E12.6/5X,*DISTANCE FROM THE COLLISION POINT TO THE FIRST FRAM
     3E AFT (IN) = *,F10.3/5X,*DEFLECTION WHERE MODIFICATION FOR FRAMES
     4STARTS (IN) = *,F10.3///)
      GO TO 139
  138 WRITE (6,137) FRAMSP,FRAM,STFF,DEFS
  137 FORMAT (///1X,*THE CRUSH FORCES ARE MODIFIED BY THE PROXIMITY TO F
     1RAMES*/5X,*FRAME SPACING (IN) = *,F10.3/5X,*FRAME CRUSH FORCE (LB)
     2 = *,E12.6/5X,*DISTANCE FROM THE COLLISION POINT TO THE FIRST FRAM
     3E TO PORT (IN) = *,F10.3/5X,*DEFLECTION WHERE MODIFICATION FOR FRA
     4MES STARTS (IN) = *,F10.3///)
  139 CONTINUE
      GO TO 71
   14 CONTINUE
      WRITE (6,550)
  550 FORMAT (//1X,*THIS IS A NON SLIDING COLLISION*)
      WRITE (6,700)
  700 FORMAT (///1X,*CAUTION----THE NO SLIDE OPTION CONSTRAINS THE LATER
     1AL DISPLACEMENT*/12X,*OF THE COLLISION POINT TO ZERO ONLY AT THE E
     2ND OF THE TIME INCREMENT*//)
      GO TO 71
   70 WRITE (6,551) XMU
  551 FORMAT (//1X,*THIS IS A SLIDING COLLISION*/10X,*MU SLIDING IS *,F7
     1.4/)
      IF (NSLIDE.EQ.2) GO TO 1138
   71 CONTINUE
```

```
      IF (ITIE.LE.0) GO TO 270
      WRITE (6,271) ETIE,PLTIE,ELONG,PLFAL
  271 FORMAT (1H1,15X,*CABLE TOW IN OPTION PARAMETERS (IN-LB-SEC UNITS)*
     1///13X,*CABLE NUMBER NOTATION*//5X,*CABLE 1 - PORT STABILIZATION C
     2ABLE*,/5X,*CABLE 2 - STBD STABILIZATION CABLE*/5X,*CABLE 3 - PORT
     3TOW CABLE*/5X,*CABLE 4 - STBD TOW CABLE*/5X,*CABLE 5 - PORT BRAKIN
     4G CABLE*/5X,*CABLE 6 - STBD BRAKING CABLE*/5X///1X,*INITIAL LOAD-D
     5EFLECTION SLOPE = *,E14.6/1X,*PLASTIC LOAD = *,E14.6/1X,*ELONGATIO
     6N AT BREAK POINT = *,F10.3/1X,*SYSTEM LOAD LIMIT VALUE =*,E14.6//)
      WRITE (6,280) (JJ,CLO(JJ),PL(JJ),JJ=1,6)
  280 FORMAT (1X,*CABLE*,2X,*INITIAL LENGTH*,8X,*PRE-LOAD*//(I4,2E16.6))
      WRITE (6,293)
  293 FORMAT (///)
      WRITE (6,281) PCLON,PCLAT,SCLON,SCLAT
  281 FORMAT (1X,*CHOCK LOCATIONS RELATIVE TO CG*//5X,*PORT CHOCK *,E14.
     16,* FORWARD*/16X,E14.6,* TO PORT*//5X,*STBD CHOCK *,E14.6,* FORWAR
     2D*/16X,E14.6,* TO STBD*///)
  270 CONTINUE
      WRITE (6,3054)
 3054 FORMAT (1H1)
      WRITE (6,3051) (D(K),F(K),K=1,NF)
 3051 FORMAT (/1X,*LOAD DEFLECTION CURVE AT THE COLLISION POINT (LB-IN U
     1NITS)*//2X,*DEFLECTION*,6X,*LOAD*/(2E16.5))
      IF (ISLIDE.GE.0) GO TO 3053
      WRITE (6,3052) (DL(K),FL(K),K=1,NL)
 3052 FORMAT (/1X,*LOAD DEFLECTION CURVE AT THE COLLISION POINT IN THE S
     2LIDE DIRECTION (LB-IN UNITS)*//2X,*DEFLECTION*,6X,*LOAD*/(2E16.5))
 3053 CONTINUE
      IF(NBUMP.LE.0) GO TO 43
      WRITE(6,42) BDEPTH,BLOC,XMUB,CUSHO
      WRITE(6,44) (BD(K),FB(K),K=1,NBU)
      DO 150 K=1,NPTS
      ZBX(K)=0.0
      ZBF(K)=0.0
      ZBFL(K)=0.0
      ZBE(K)=0.0
  150 ZBEL(K)=0.0
```

```
   43 CONTINUE                                                          DOCK
   42 FORMAT(////5X,*A SIDE COLLISION BUMPER IS DEFINED*//1X,           DOCK
     1*BUMPER DEPTH(IN) = *,F10.3/1X,*BUMPER FORCE IS APPLIED *,F10.3,  DOCK
     2* INCHES FORWARD OF CENTER OF GRAVITY*/1X,*FRICTION COEFFICIENT IS DOCK
     3 *,F10.3/1X,*CUSHION PROTRUDES *,F10.3* INCHES BEYOND HARD STRUCTU DOCK
     +RE*///)                                                           DOCK
   44 FORMAT(5X,*BUMPER LOAD-DEFLECTION CURVE (LB-IN UNITS)*//2X,       DOCK
     1*DEFLECTION*,6X,*LOAD*//(2E16.6))                                 DOCK
      WRITE (6,3055)                                                    DOCK
 3055 FORMAT (/////)                                                    DOCK
      WRITE (6,759)                                                     DOCK
  759 FORMAT (10X,*  SIGN CONVENTION (CRAFT COORDINATE SYSTEM) *//1X,*POS DOCK
     1ITIVE X DIRECTION - STARBOARD*/1X,*POSITIVE Y DIRECTION - FORWARD* DOCK
     2/1X,*POSITIVE ROTATION - CLOCKWISE*///1X,*GROUND COORDINATE SYSTEM DOCK
     2 REFERENCES*//1X,*POSITIVE CRAFT ROTATION RELATIVE TO GROUND COORD DOCK
     3INATE SYSTEM IS POSITIVE*/1X,*IF ROTATION IS ZERO - X-CRAFT IS X-G DOCK
     +ROUND AND Y-CRAFT IS Y-GROUND*/1X,*COORDINATE SYSTEM ORIGIN IS AT  DOCK
     5THE INITIAL LOCATION OF THE POINT OF INTEREST*///1X,*INITIAL VELOC DOCK
     6ITY VECTOR ORIENTATION (GROUND COORDINATE SYSTEM)*//1X,*POSITIVE A DOCK
     7T AN ANGLE CLOCKWISE FROM THE POSITIVE Y-GROUND DIRECTION*)        DOCK
      WRITE (6,102) T,XBC,YBC,VBXC,VBYC,FT,FD                           DOCK
  102 FORMAT (1H1,*CRAFT COORDINATE SYSTEM RESPONSE AT POINT OF COLLISIO DOCK
     1N (LB-IN-SEC UNITS) *///1X,*TIME*,14X,*X DISPLACEMENT*,4X,*Y DISPL DOCK
     2ACEMENT*,4X,*X VELOCITY*,8X,*Y VELOCITY*,8X,*LATERAL FORCE*,3X,*CR DOCK
     3USH FORCE*//(1X,7(E12.6,6X)))                                     DOCK
      NP=0                                                              DOCK
      YBCOLD=0.0                                                        DOCK
      ITTEST=0                                                          DOCK
      XFTLST=0.0                                                        DOCK
      ECFR(1)=0.0                                                       DOCK
      ECCR(1)=0.0                                                       DOCK
      DTH=1.0                                                           DOCK
      YCRT=0.0                                                          DOCK
      YCRB=0.0                                                          DOCK
      NENT=0                                                            DOCK
      NEND=0                                                            DOCK
      DO 11 I=2,NPTS                                                    DOCK
      T=T+DT                                                            DOCK
```

```
      THETAT=X(3,I-1)                                                   DOCK 343
      IF(IFLAG.GT.0) GO TO 350                                          DOCK 344
      Z1=CW/COS(THETAT)                                                 DOCK 345
      Z2=XBC/COS(THETAT)                                                DOCK 346
      Z1=Z1-Z2                                                          DOCK 347
      IF(Z1.GT.WDW) IFLAG=1                                             DOCK 348
      IF(IFLAG.GT.0) TFLAG=T                                            DOCK 349
  350 CONTINUE                                                          DOCK 350
      B=BB-YBC                                                          DOCK 351
      E=EE-XBC                                                          DOCK 352
      COFF=CRL-CGB+B                                                    DOCK 353
      IF (COFF.GT.0.0) GO TO 899                                        DOCK 354
      NPTST=I-1                                                         DOCK 355
      T=T-DT                                                            DOCK 356
      GOTO 12                                                           DOCK 357
  899 CONTINUE                                                          DOCK 358
      IF (E) 1100,1898,1101                                             DOCK 359
 1100 ETE=-E                                                            DOCK 360
      IF (ETE.LE.CGS) GO TO 1898                                        DOCK 361
      GO TO 1899                                                        DOCK 362
 1101 IF (E.LE.CGP) GO TO 1898                                          DOCK 363
      IF(NBOW.LE.0) GO TO 1898                                          DOCK 364
 1899 NPTST=I-1                                                         DOCK 365
      T=T-DT                                                            DOCK 366
      GOTO 12                                                           DOCK 367
 1898 CONTINUE                                                          DOCK 368
      IF (NCON.LE.0) GO TO 807                                          DOCK 369
      CPB=CGB-B                                                         DOCK 370
      TESW=CW*COS(THETAT)-CPB*SIN(THETAT)-XBC*COS(THETAT)               DOCK 371
      DSW=TESW-WDW                                                      DOCK 372
      DSWB=DSW                                                          DOCK 373
      DDSW=DSW-DSWLST                                                   DOCK 374
      IF (DDSW.LT.0.0) GO TO 805                                        DOCK 375
      IF (VOLAT.GE.0.0) GO TO 805                                       DOCK 376
      DSWLST=DSW                                                        DOCK 377
      IF (TOC.GT.0.0) GO TO 873                                         DOCK 378
      TOC=T                                                             DOCK 379
  873 CONTINUE                                                          DOCK 380
```

```
      IF(DSW.LT.DO(1))  GO TO 27
      DO 861 K=1,NO
      IF (DSW-DO(K)) 863,862,861
  862 FOC=FO(K)
      GO TO 864
  863 FOC=FO(K-1)+(DSW-DO(K-1))/(DO(K)-DO(K-1))*(FO(K)-FO(K-1))
      GO TO 864
  861 CONTINUE
      FOC=FO(20)
  864 CONTINUE
      FOT=XMUC*FOC
      GO TO 804
  805 IF(NREBO.GT.0) GO TO  873
   27 CONTINUE
      FOC=0.0
      FOT=0.0
      DDSW=0.0
      DDYB=0.0
  804 CONTINUE
      IF (VOBYC.GT.0.0)  FOT=-FOT
      IF (VOBYC.EQ.0.0)  FOT=0.0
      DD(I,2)=FOT
      DD(I,3)=FOC
  807 CONTINUE
      IF (NTIE.LE.0) GO TO  292
      DO 235 K=1,6
  235 CF(K,I)=0.0
      CPB=CGB-BB+Y3C
      PLTEST=CPB*COS(THETAT)+CW*SIN(THETAT)-CGP+PCLON
      SLTEST=CPB*COS(THETAT)-CGP+SCLON
      HOR=SQRT(CLO(3)*CLO(3)-TCH2)
      HOR=HOR+YPCF
      CL(3,I-1)=SQRT(HOR*HOR+TCH2)
      HOR=SQRT(CLO(4)*CLO(4)-TCH2)
      HOR=HOR+YSCF
      CL(4,I-1)=SQRT(HOR*HOR+TCH2)
      HOR=SQRT(CLO(5)*CLO(5)-TCH2)
      HOR=HOR+YPCA
```

```
      CL(5,I-1)=SQRT(HOR*HOR+TCH2)
      HOR=SQRT(CLO(6)*CLO(6)-TCH2)
      HOR=HOR+YSCA
      CL(6,I-1)=SQRT(HOR*HOR+TCH2)
      IF (CL(3,I-1).LE.CLM(3)) GO TO 236
      IF (KFLG3.GT.0) GO TO 236
      STRAIN=YPCF/CLO(3)+STR(3)
      IF (STRAIN.LT.ELONG) GO TO 245
      KFLG3=1
      GO TO 236
  245 IF (STRAIN.GE.STRP) GO TO 272
      IF (STRAIN.GE.STRF) GO TO 237
      CF(3,I)=STRAIN*ETIE-PL(3)
      GO TO 236
  272 CF(3,I)=PLTIE-PL(3)
      GO TO 236
  237 CF(3,I)=PLFAL-PL(3)
  236 IF (CL(5,I-1).LE.CLM(5)) GO TO 238
      IF (KFLG5.GT.0) GO TO 238
      STRAIN=YPCA/CLO(5)+STR(5)
      IF (STRAIN.LT.ELONG) GO TO 246
      KFLG5=1
      GO TO 238
  246 IF (STRAIN.GE.STRP) GO TO 273
      IF (STRAIN.GE.STRF) GO TO 239
      CF(5,I)=STRAIN*ETIE-PL(5)
      GO TO 238
  273 CF(5,I)=PLTIE-PL(3)
      GO TO 238
  239 CF(5,I)=PLFAL-PL(5)
  238 IF (CL(4,I-1).LE.CLM(4)) GO TO 240
      IF (KFLG4.GT.0) GO TO 240
      STRAIN=YSCF/CLO(4)+STR(4)
      IF (STRAIN.LT.ELONG) GO TO 247
      KFLG4=1
      GO TO 240
  247 IF (STRAIN.GE.STRP) GO TO 274
      IF (STRAIN.GE.STRF) GO TO 241
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      CF(4,I)=STRAIN*ETIE-PL(4)                                         DOCK 457
      GO TO 240                                                         DOCK 458
  274 CF(4,I)=PLTIE-PL(4)                                               DOCK 459
      GO TO 240                                                         DOCK 460
  241 CF(4,I)=PLFAL-PL(4)                                               DOCK 461
  240 IF (CL(6,I-1).LE.CLM(6)) GO TO 242                                DOCK 462
      IF (KFLG6.GT.0) GO TO 242                                         DOCK 463
      STRAIN=YSCA/CLO(6)+STR(6)                                         DOCK 464
      IF (STRAIN.LT.ELONG) GO TO 248                                    DOCK 465
      KFLG6=1                                                           DOCK 466
      GO TO 242                                                         DOCK 467
  248 IF (STRAIN.GE.STRP) GO TO 275                                     DOCK 468
      IF (STRAIN.GE.STRF) GO TO 243                                     DOCK 469
      CF(6,I)=STRAIN*ETIE-PL(6)                                         DOCK 470
      GO TO 242                                                         DOCK 471
  275 CF(6,I)=PLTIE-PL(6)                                               DOCK 472
      GO TO 242                                                         DOCK 473
  243 CF(6,I)=PLFAL-PL(6)                                               DOCK 474
  242 CONTINUE                                                          DOCK 475
      HSL=-CPB*SIN(THETAT)                                              DOCK 476
      HPL=HDW-HSL-CM*COS(THETAT)                                        DOCK 477
      CL(1,I-1)=SQRT(TCH2+HPL*HPL)                                      DOCK 478
      CL(2,I-1)=SQRT(TCH2+HSL*HSL)                                      DOCK 479
      IF (CL(1,I-1).LE.CLM(1)) GO TO 231                                DOCK 480
      IF (KFLG1.GT.0) GO TO 231                                         DOCK 481
      STRAIN=(CL(1,I-1)-CLO(1))/CLO(1)+STR(1)                           DOCK 482
      IF (STRAIN.LT.ELONG) GO TO 250                                    DOCK 483
      KFLG1=1                                                           DOCK 484
      GO TO 231                                                         DOCK 485
  250 IF (STRAIN.GE.STRP) GO TO 277                                     DOCK 486
      IF (STRAIN.GE.STRF) GO TO 249                                     DOCK 487
      CF(1,I)=ETIE*STRAIN-PL(1)                                         DOCK 488
      GO TO 231                                                         DOCK 489
  277 CF(1,I)=PLTIE-PL(1)                                               DOCK 490
      GO TO 231                                                         DOCK 491
  249 CF(1,I)=PLFAL-PL(1)                                               DOCK 492
  231 IF (CL(2,I-1).LE.CLM(2)) GO TO 221                                DOCK 493
      IF (KFLG2.GT.0) GO TO 221                                         DOCK 494
```

```
      STRAIN=(CL(2,I-1)-CLO(2))/CLO(2)+STR(2)                          DOCK
      IF (STRAIN.LT.ELONG) GO TO 223                                   DOCK
      KFLG2=1                                                          DOCK
      GO TO 221                                                        DOCK
  223 IF (STRAIN.GE.STRP) GO TO 278                                    DOCK
      IF (STRAIN.GE.STRF) GO TO 222                                    DOCK
      CF(2,I)=ETIE*STRAIN-PL(2)                                        DOCK
      GO TO 221                                                        DOCK
  278 CF(2,I)=PLTIE-PL(2)                                              DOCK
      GO TO 221                                                        DOCK
  222 CF(2,I)=PLFAL-PL(2)                                              DOCK
  221 CONTINUE                                                         DOCK
      DO 267 K=1,6                                                     DOCK
      TESK=SQRT(CLM(K)*CLM(K)+TCH2)                                    DOCK
      GAMA=ATAN(TCHGT/TESK)                                            DOCK
  267 CF(K,I-1)=CF(K,I-1)*COS(GAMA)                                    DOCK
      IF (W(3,I-1).GT.0.0) GO TO 294                                   DOCK
      CF(1,I)=0.0                                                      DOCK
      CF(4,I)=0.0                                                      DOCK
      CF(5,I)=0.0                                                      DOCK
      GO TO 295                                                        DOCK
  294 CONTINUE                                                         DOCK
      CF(2,I)=0.0                                                      DOCK
      CF(3,I)=0.0                                                      DOCK
      CF(5,I)=0.0                                                      DOCK
  295 CONTINUE                                                         DOCK
      IF (PLTEST.LT.CLOT5) GO TO 297                                   DOCK
      IF (CF(5,I).GT.CF(4,I)) CF(5,I)=CF(4,I)                          DOCK
      IF (CF(4,I).GT.CF(5,I)) CF(4,I)=CF(5,I)                          DOCK
      GO TO 300                                                        DOCK
  297 CF(5,I)=0.0                                                      DOCK
      CF(4,I)=0.0                                                      DOCK
      YPCA=0.0                                                         DOCK
      YSCF=0.0                                                         DOCK
  300 IF (SLTEST.LT.CLOT6) GO TO 298                                   DOCK
      IF (CF(3,I).GT.CF(6,I)) CF(3,I)=CF(6,I)                          DOCK
      IF (CF(6,I).GT.CF(3,I)) CF(6,I)=CF(3,I)                          DOCK
      GO TO 299
```

```
  298 CF(6,I)=0.0                                               DOCK
      CF(3,I)=0.0                                               DOCK
      YPCF=0.0                                                  DOCK
      YSCA=0.0                                                  DOCK
  299 CONTINUE                                                  DOCK
  292 CONTINUE                                                  DOCK
      ALPA=ATAN(B/E)                                            DOCK
      CALP=COS(ALPA)                                            DOCK
      R=SQRT(B*B+E*E)                                           DOCK
      IF (NBOW.LT.1) GO TO 75                                   DOCK
      XCR=YBC                                                   DOCK
      YCR=ABS(XBC)                                              DOCK
      XLAT=XBC                                                  DOCK
      XNORM=YBC                                                 DOCK
      GO TO 76                                                  DOCK
   75 XCR=XBC                                                   DOCK
      YCR=ABS(YBC)                                              DOCK
      XLAT=YBC                                                  DOCK
      XNORM=XBC                                                 DOCK
   76 CONTINUE                                                  DOCK
      IF (XCR.GE.D(1)) GO TO 74                                 DOCK
      FC=0.0                                                    DOCK
      FT=0.0                                                    DOCK
      GO TO 64                                                  DOCK
   74 CONTINUE                                                  DOCK
      DO 61 J=1,NF                                              DOCK
      IF (XCR-D(J)) 63,62,61                                    DOCK
   62 FC=F(J)                                                   DOCK
      GO TO 64                                                  DOCK
   63 FC=F(J-1)+(XCR-D(J-1))/(D(J)-D(J-1))*(F(J)-F(J-1))        DOCK
      GO TO 64                                                  DOCK
   61 CONTINUE                                                  DOCK
      FC=F(20)                                                  DOCK
   64 CONTINUE                                                  DOCK
      IF (NSLIDE.LT.2) GO TO 131                                DOCK
      IF (XNORM.LE.DEFS) GO TO 131                              DOCK
      STTF=STFF-XLAT                                            DOCK
  140 IF (STTF.GE.0.0) GO TO 133                                DOCK
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```
      STTF=STTF+FRAMSP                                                  DOCK
      GO TO 140                                                         DOCK
  133 IF (STTF.LE.FRAMSP) GO TO 134                                     DOCK
      STTF=STTF-FRAMSP                                                  DOCK
      GO TO 140                                                         DOCK
  134 DAF=STTF                                                          DOCK
      DFF=FRAMSP-DAF                                                    DOCK
      XSTIF=DAF                                                         DOCK
      IF (DFF.LT.DAF) XSTIF=DFF                                         DOCK
      IF (XSTIF.GT.0.0) GO TO 130                                       DOCK
      FC=FRAM                                                           DOCK
      GO TO 131                                                         DOCK
  130 Y=0.3904*XSTIF**(-1.10339)*EXP(0.92695*XSTIF)                     DOCK
      FC=FC*Y                                                           DOCK
      REACT=FC*(FRAMSP-XSTIF)/FRAMSP                                    DOCK
      IF (REACT.GT.FRAM) FC=FRAM*FRAMSP/(FRAMSP-XSTIF)                  DOCK
  131 CONTINUE                                                          DOCK
      IF (ISLIDE.GE.0) GO TO 96                                         DOCK
      IF (XCR.GE.D(1)) GO TO 97                                         DOCK
      FT=0.0                                                            DOCK
      GO TO 96                                                          DOCK
   97 CONTINUE                                                          DOCK
      DO 93 J=1,NL                                                      DOCK
      IF (YCR-DL(J)) 95,94,93                                           DOCK
   94 FT=FL(J)                                                          DOCK
      GO TO 96                                                          DOCK
   95 FT=FL(J-1)+(YCR-DL(J-1))/(DL(J)-DL(J-1))*(FL(J)-FL(J-1))          DOCK
      GO TO 96                                                          DOCK
   93 CONTINUE                                                          DOCK
      FT=FL(20)                                                         DOCK
   96 CONTINUE                                                          DOCK
      IF (NROW.LT.1) GO TO 77                                           DOCK
      IF (VBYC.GT.0.0) GO TO 703                                        DOCK
      NENT=1                                                            DOCK
      IF (I.LE.5) NENT=0                                                DOCK
      FC=0.0                                                            DOCK
  703 CONTINUE                                                          DOCK
      IF (ISLIDE) 91,81,92                                              DOCK
```

```
92 IF (NENT.EQ.0) GO TO 23                                    DOCK       609
   IF(NFLY.GT.0) GU TO 23                                     DOCK       610
   FT=0.0                                                     DOCK       611
   NEND=1                                                     DOCK       612
   IF (I.LE.5) NEND=0                                         DOCK       613
   GO TO 78                                                   DOCK       614
23 FT=-XMU*FC                                                 DOCK       615
   IF (VBXC.LT.0.0) FT=-FT                                    DOCK       616
   GO TO 78                                                   DOCK       617
91 IF (YBC.GT.0.0) GO TO 21                                   DOCK       618
   FT=0.0                                                     DOCK       619
   FC=0.0                                                     DOCK       620
   NEND=1                                                     DOCK       621
   IF (I.LE.5) NEND=0                                         DOCK       622
   GO TO 78                                                   DOCK       623
21 IF (VBXC.GT.0.0) FT=-FT                                    DOCK       624
   IF (XBC.GT.YCRT) GO TC 45                                  DOCK       625
   IF (XBC.LT.YCRB) GO TO 47                                  DOCK       626
   FT=0.0                                                     DOCK       627
   GO TO 78                                                   DOCK       628
45 YCRT=XBC                                                   DOCK       629
   GO TO 78                                                   DOCK       630
47 YCRB=XBC                                                   DOCK       631
   GO TO 78                                                   DOCK       632
81 CONTINUE                                                   DOCK       633
   IF (NENT.EQ.0) GO TO 26                                    DOCK       634
   IF (YBC.GT.0.0) GO TO 26                                   DOCK       635
   FT=0.0                                                     DOCK       636
   NEND=1                                                     DOCK       637
   GO TO 78                                                   DOCK       638
26 CONTINUE                                                   DOCK       639
   XTT=2.0*XM*XIC/(XIC*DT*DT+XM*B*B*DT*DT)                    DOCK       640
   TTS=SIN(THETAT)*V(2,I-1)*DT                                DOCK       641
   TTC=-COS(THETAT)*V(1,I-1)*DT                               DOCK       642
   TT=-B*V(3,I-1)*DT-FC*E*B*DT*DT*0.5/XIC                     DOCK       643
   FT=XTT*(TTS+TTC+TT)                                        DOCK       644
   GO TO 78                                                   DOCK       645
77 CONTINUE                                                   DOCK       646
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      IF (VBXC.GT.0.0) GO TO 704                                        DOCK 647
      NENT=1                                                            DOCK 648
      IF (I.LE.5) NENT=0                                                DOCK 649
      FC=0.0                                                            DOCK 650
  704 CONTINUE                                                          DOCK 651
      IF(NBUMP.LE.0) GO TO 37                                           DOCK 652
      FBUMPT=0.0                                                        DOCK 653
      FBUMP=0.0                                                         DOCK 654
      BBB=BLOC-B                                                        DOCK 655
      BCRUSH =BDEPTH+BBB*SIN(X(3,I-1))+XBC-CUSHO                        DOCK 656
      BLATT=BLAT-BCRUSH                                                 DOCK 657
      IF(BCRUSH.LE.BCRMX) GO TO 37                                      DOCK 658
      VBBC=VXC+V(3,I-1)*BLOC                                            DOCK 659
      IF(VBBC.LE.0.0) GO TO 37                                          DOCK 660
      DO 32 J=1,NBU                                                     DOCK 661
      IF(BCRUSH-BD(J)) 35,34,32                                         DOCK 662
   34 FBUMP=FB(J)                                                       DOCK 663
      GO TO 36                                                          DOCK 664
   35 FBUMP=FB(J-1)+(BCRUSH-BD(J-1))/(BD(J)-BD(J-1))*(FB(J)-FB(J-1))    DOCK 665
      GO TO 36                                                          DOCK 666
   32 CONTINUE                                                          DOCK 667
      FBUMP=FB(20)                                                      DOCK 668
   36 CONTINUE                                                          DOCK 669
      FBUMPT=FBUMP*XMUB                                                 DOCK 670
      IF(VBYC.GE.0.0) FBUMPT=-FBUMPT                                    DOCK 671
      BCRMX=BCRUSH                                                      DOCK 672
      ZBX(I)=BCRUSH                                                     DOCK 673
      ZBF(I)=FBUMP                                                      DOCK 674
      ZBFL(I)=FBUMPT                                                    DOCK 675
   37 CONTINUE                                                          DOCK 676
      IF (NSLIDE) 66,67,68                                              DOCK 677
   68 IF (NENT.EQ.0) GO TO 24                                           DOCK 678
      IF(NFLY.GT.0) GO TO 24                                            DOCK 679
      FT=0.0                                                            DOCK 680
      NEND=1                                                            DOCK 681
      GO TO 78                                                          DOCK 682
   24 FT=-XMU*FC                                                        DOCK 683
      IF (VBYC.LT.0.0) FT=-FT                                           DOCK 684
```

```
      GO TO 78
   65 IF (XBC.GT.0.0) GO TO 22
      FT=0.0
      FC=0.0
      NEND=1
      GO TO 78
   22 IF (VBYC.GT.0.0)  FT=-FT
      IF (YBC.GT.YCRT)  GO TO 52
      IF (YBC.LT.YCRB)  GO TO 53
      FT=0.0
      GO TO 78
   52 YCRT=YBC
      GO TO 78
   53 YCRB=YBC
      GO TO 78
   67 CONTINUE
      IF (NENT.EQ.0) GO TO 25
      IF (XBC.GT.0.0) GO TO 25
      FT=0.0
      NEND=1
      GO TO 78
   25 CONTINUE
      XTT=2.0*XM*XIC/(XIC*DT*DT+XM*E*E*DT*DT)
      TTS=-SIN(THETAT)*V(1,I-1)*DT
      TTC=-COS(THETAT)*V(2,I-1)*DT
      TT=E*V(3,I-1)*DT-FC*E*B*DT*DT*0.5/XIC
      FT=XTT*(TTS+TTC+TT)
   78 CONTINUE
      IF (NBOW.LT.1) GO TO 83
      ALPHA=(FC*E+FT*B)/XIC
      GO TO 84
   83 ALPHA=(-FC*B-FT*E)/XIC
   84 CONTINUE
      IF (NBOW.LT.1) GO TO 85
      FX=FT*COS(THETAT)-FC*SIN(THETAT)
      FY=-FT*SIN(THETAT)-FC*COS(THETAT)
      GO TO 86
   85 FX=FT*SIN(THETAT)-FC*COS(THETAT)
```

```
      FY=FT*COS(THETAT)+FC*SIN(THETAT)                                  DOCK
      IF (NCON.LE.0) GO TO 801                                          DOCK
      DLAT=CGS*COS(THETAT)-DSHLST-CGB*SIN(THETAT)                       DOCK
      DVERT=CGB*COS(THETAT)+CGS*SIN(THETAT)                             DOCK
      ALPHA=ALPHA+(FOT*DLAT+FOC*DVERT)/XIC                              DOCK
      FX=FX+FOC                                                         DOCK
      FY=FY+FOT                                                         DOCK
  801 CONTINUE                                                          DOCK
      IF (NTIE.LE.0) GO TO 290                                          DOCK
      ALPHA=ALPHA+(CF(2,I)*SCLON+CF(6,I)*SCLAT-CF(4,I)*SCLAT+CF(3,I)*PCL DOCK
     1AT-CF(1,I)*PCLON-CF(5,I)*PCLAT)/XIC                               DOCK
      FY=FY+CF(3,I)+CF(4,I)-CF(5,I)-CF(6,I)                             DOCK
      FX=FX+CF(2,I)-CF(1,I)                                             DOCK
  290 CONTINUE                                                          DOCK
      IF(NBUMP.LE.0) GO TO 54                                           DOCK
      FX=FX-FBUMP*COS(THETAT)+FBUMPT*SIN(THETAT)                        DOCK
      FY=FY+FBUMPT*COS(THETAT)+FBUMP*SIN(THETAT)                        DOCK
      ALPHA=ALPHA-1.0/XIC*(FBUMP*BLOC+FBUMPT*BLATT)                     DOCK
   54 CONTINUE                                                          DOCK
   86 CONTINUE                                                          DOCK
      V(3,I)=V(3,I-1)+ALPHA*DT                                          DOCK
      DTH=ALPHA*DT*DT/2.+V(3,I-1)*DT                                    DOCK
      X(3,I)=X(3,I-1)+DTH                                               DOCK
      V(1,I)=V(1,I-1)+FX*DT/XM                                          DOCK
      V(2,I)=V(2,I-1)+FY*DT/XM                                          DOCK
      DX=V(1,I-1)*DT+FX*DT*DT*0.5/XM                                    DOCK
      DY=V(2,I-1)*DT+FY*DT*DT*0.5/XM                                    DOCK
      X(1,I)=X(1,I-1)+DX                                                DOCK
      X(2,I)=X(2,I-1)+DY                                                DOCK
      ZETA=ALPA-THETAT                                                  DOCK
      VB(1,I)=V(1,I)+V(3,I)*R*SIN(ZETA)                                 DOCK
      VB(2,I)=V(2,I)-V(3,I)*R*COS(ZETA)                                 DOCK
      VXC=-V(2,I)*SIN(THETAT)+V(1,I)*COS(THETAT)                        DOCK
      VYC=V(2,I)*COS(THETAT)+V(1,I)*SIN(THETAT)                         DOCK
      VBXC=VXC+V(3,I)*B                                                 DOCK
      VBYC=VYC-V(3,I)*E                                                 DOCK
      IF (NCON.LE.0) GO TO 806                                          DOCK
      VOBYC=V(2,I)+V(3,I)*DLAT                                          DOCK
```

```
      VOLAT=V(1,I)+V(3,I)*DVERT                                        DOCK
      YBOC=YBOC+DY+DTH*DLAT                                            DOCK
  806 CONTINUE                                                         DOCK
      XBC=XBC+DX*COS(THETAT)-DY*SIN(THETAT)+DTH*B                      DOCK
      YBC=YBC+DX*SIN(THETAT)+DY*COS(THETAT)-DTH*B                      DOCK
      XB(1,I)=XBC*COS(THETAT)+YBC*SIN(THETAT)                          DOCK
      XB(2,I)=-XBC*SIN(THETAT)+YBC*COS(THETAT)                         DOCK
      IF (NBOW.LT.1) GO TO 87                                          DOCK
      DYB=YBC-YBCLST                                                   DOCK
      YBCLST=YBC                                                       DOCK
      DEC=FC*DYB                                                       DOCK
      DXC=XBC-XFTLST                                                   DOCK
      XMEC=-FT*DXC                                                     DOCK
      XFTLST=XBC                                                       DOCK
      GO TO 88                                                         DOCK
   87 DYB=XBC-YBCLST                                                   DOCK
      YBCLST=XBC                                                       DOCK
      DEC=FC*DYB                                                       DOCK
      DXC=YBC-XFTLST                                                   DOCK
      XMEC=-FT*DXC                                                     DOCK
      XFTLST=YBC                                                       DOCK
      IF (NCON.LE.0) GO TO 874                                         DOCK
      DDYB=YBOC-YBOCST                                                 DOCK
      YBOCST=YBOC                                                      DOCK
      XMOC=XMOC-DDYB*FOT                                               DOCK
      CPB=CGB-BB+YBC                                                   DOCK
      TESW=CW*COS(X(3,I))-CPB*SIN(X(3,I))-XBC*COS(X(3,I))              DOCK
      DSW=TESW-WDW                                                     DOCK
      DDSW=DSW-DSWB                                                    DOCK
      IF (DSW.GT.DSWLST) DSWLST=DSW                                    DOCK
      DD(I,1)=DSW                                                      DOCK
      XMOCR=XMOCR+DDSW*FOC                                             DOCK
      DD(I,4)=XMOC                                                     DOCK
      DD(I,5)=XMOCR                                                    DOCK
      XMOP=XMOC+XMOCR                                                  DOCK
  874 CONTINUE                                                         DOCK
      IF (ITIE.LE.0) GO TO 265                                         DOCK
      CPB=CGB-BB+YBC                                                   DOCK
```

```
      YPCF=YPCF-DTH*PCLAT                                          DOCK
      YPCA=YPCA+DTH*PCLAT                                          DOCK
      YSCA=YSCA-DTH*SCLAT                                          DOCK
      YSCF=YSCF+DTH*SCLAT                                          DOCK
      HOR=SQRT(CLO(3)*CLO(3)-TCH2)                                 DOCK
      HOR=HOR+YPCF                                                 DOCK
      CL(3,I)=SQRT(HOR*HOR+TCH2)                                   DOCK
      HOR=SQRT(CLO(4)*CLO(4)-TCH2)                                 DOCK
      HOR=HOR+YSCF                                                 DOCK
      CL(4,I)=SQRT(HOR*HOR+TCH2)                                   DOCK
      HOR=SQRT(CLO(5)*CLO(5)-TCH2)                                 DOCK
      HOR=HOR+YPCA                                                 DOCK
      CL(5,I)=SQRT(HOR*HOR+TCH2)                                   DOCK
      HOR=SQRT(CLO(6)*CLO(6)-TCH2)                                 DOCK
      HOR=HOR+YSCA                                                 DOCK
      CL(6,I)=SQRT(HOR*HOR+TCH2)                                   DOCK
      HS=-BPB*SIN(X(3,I))                                          DOCK
      HP=WDW-HS-CW*COS(X(3,I))                                     DOCK
      CL(1,I)=SQRT(TCH2+HP*HP)                                     DOCK
      CL(2,I)=SQRT(TCH2+HS*HS)                                     DOCK
      EP(1,I)=EP(1,I-1)+CF(3,I)*(-DTH*PCLAT)                       DOCK
      EP(2,I)=EP(2,I-1)+CF(1,I)*(HP-HPL)                           DOCK
      EP(3,I)=EP(3,I-1)+CF(5,I)*(DTH*PCLAT)                        DOCK
      ES(1,I)=ES(1,I-1)+CF(4,I)*(DTH*SCLAT)                        DOCK
      ES(2,I)=ES(2,I-1)+CF(2,I)*(HS-HSL)                           DOCK
      ES(3,I)=ES(3,I-1)+CF(6,I)*(-DTH*SCLAT)                       DOCK
      DO 260 J=1,6                                                 DOCK
      IF (CF(J,I).LE.0.0) GO TO 260                                DOCK
      CLM(J)=CL(J,I)                                               DOCK
  260 CONTINUE                                                     DOCK
  265 CONTINUE                                                     DOCK
   88 ECFR(I)=ECFR(I-1)+XMEC                                       DOCK
      ECCR(I)=ECCR(I-1)+DEC                                        DOCK
      IF(NBUMP.LE.0) GO TO 31                                      DOCK
      DCRUSH=DX*COS(THETAT)-DY*SIN(THETAT)+DTH*BLOC                DOCK
      EBUMP=EBUMP+DCRUSH*FBUMP                                     DOCK
      DSLIDE=DX*SIN(THETAT)+DY*COS(THETAT)-DTH*BLATT               DOCK
      EBUMPT=EBUMPT-FBUMPT*DSLIDE                                  DOCK
```

```
      ZBL(I)=EBUMP                                                      DOCK
      ZBEL(I)=EBUMPT                                                    DOCK
   31 CONTINUE                                                          DOCK
      NP=NP+1                                                           DOCK
      IF (NP-NPT) 50,51,51                                              DOCK
   51 CONTINUE                                                          DOCK
      WRITE (6,104) T,XBC,YBC,VBXC,VBYC,FT,FC                           DOCK
  104 FORMAT (1X,4(E12.6,6X),E12.6,5X,E13.6,5X,E12.6)                   DOCK
      NP=0                                                              DOCK
   50 CONTINUE                                                          DOCK
      IF (IEND.EQ.0) GO TO 10                                           DOCK
      IF (I.LT.5) GO TO 10                                              DOCK
      IF (IFLY.GT.0) GO TO 69                                           DOCK
      NPTST=I                                                           DOCK
      GO TO 12                                                          DOCK
   69 YCRT=0.0                                                          DOCK
      YCRB=0.0                                                          DOCK
   10 CONTINUE                                                          DOCK
      GO TO 13                                                          DOCK
   12 NPTS=NPTST                                                        DOCK
   13 CONTINUE                                                          DOCK
      IF(IFLAG.LE.0) GO TO 351                                          DOCK
      WRITE(6,352) TFLAG                                                DOCK
  352 FORMAT(///10X,*COLLISION POINT SHIFTS TO MIDLENGTH OF OPPOSITE SID DOCK
     1E AT TIME *,E16.6,* SECONDS*//)                                   DOCK
  351 CONTINUE                                                          DOCK
      WRITE (6,3056) T,XBC,YBC                                          DOCK
 3056 FORMAT (///1X,*COLLISION ENDS AT TIME = *,E14.6,* SECONDS*/       DOCK
     15X,*  FINAL X DISPLACEMENT = *,E14.6,* INCHES*/                   DOCK
     25X,*  FINAL Y DISPLACEMENT = *,E14.6,* INCHES*//)                 DOCK
      IF (ICON.LE.0) GO TO 827                                          DOCK
      WRITE (6,828) DSWLST                                              DOCK
      IF (DSWLST.LE.0.0) GO TO 871                                      DOCK
      WRITE (6,870) TOC,XMOCR,XMOC,XMOP                                 DOCK
  871 CONTINUE                                                          DOCK
  870 FORMAT (15X,*INITIAL CONTACT OCCURED AT TIME = *,E14.6,* SECONDS*/ DOCK
     115X,*ENERGY ABSORBED BY CRUSHING OF THE OPPOSITE SIDE = *,E14.6,*  DOCK
     2IN-LBS*/15X,*ENERGY ABSORBED BY FRICTION ON THE OPPOSITE SIDE = *, DOCK
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   3E14.6,* IN-LBS*/15X,*TOTAL ENERGY ABSORBED ON THE OPPOSITE SIDE =  DOCK
   4*,E14.6,* IN-LBS*)                                                 DOCK
828 FORMAT (/////10X,*OPPOSITE CORNER CONTACT WAS INVESTIGATED AND A C DOCK
   1RUSH DEFLECTION OF *,E14.6,* INCHES WAS OBSERVED*)                 DOCK
    GO TO 829                                                          DOCK
827 WRITE (6,830)                                                      DOCK
830 FORMAT(/////10X,*OPPOSITE CORNER CONTACT WAS NOT INVESTIGATED*)    DOCK
829 CONTINUE                                                           DOCK
    IF(NBUMP.LE.0) GO TO 17                                            DOCK
    WRITE(6,55) BCRMX,EBUMP,EBUMPT                                     DOCK
 55 FORMAT(////5X,*SIDE BUMPER COLLISION IS INVESTIGATED*/1X,          DOCK
   1*MAXIMUM CRUSH = *,F10.3,* INCHES*/1X,*BUMPER CRUSH ENERGY = *,    DOCK
   2E16.5,* IN-LBS*/1X,*BUMPER FRICTION ENERGY = *,E16.5,* IN-LBS*     DOCK
   3////)                                                              DOCK
 17 CONTINUE                                                           DOCK
    NP=NPT-1                                                           DOCK
    T=-DT                                                              DOCK
    WRITE (6,123)                                                      DOCK
123 FORMAT (1H1,*GROUND COORDINATE SYSTEM RESPONSE AT POINT OF COLLISI DOCK
   1ON (LB-IN-SEC UNITS) *///1X,*TIME*,14X,*X DISPLACEMENT*,4X,*Y DISP DOCK
   2LACEMENT*,4X,*X VELOCITY*,8X,*Y VELOCITY*,8X,*ENERGY ABSORBED*,3X, DOCK
   3*ENERGY ABSORBED*/93X,* LATERALLY *,4X,*BY CRUSHING*/)             DOCK
    DO 20 I=1,NPTS                                                     DOCK
    T=T+DT                                                             DOCK
    NP=NP+1                                                            DOCK
    IF(NP.LT.NPT) GO TO 650                                            DOCK
    NP=0                                                               DOCK
    WRITE (6,103) T,XB(1,I),XB(2,I),VB(1,I),VB(2,I),ECFR(I),ECCR(I)    DOCK
103 FORMAT (1X,7(E12.6,5X))                                            DOCK
650 CONTINUE                                                           DOCK
 20 CONTINUE                                                           DOCK
    T=-DT                                                              DOCK
    NP=NPT-1                                                           DOCK
    WRITE (6,105)                                                      DOCK
105 FORMAT (1H1,*GROUND COORDINATE SYSTEM RESPONSE AT THE CRAFT CENTER DOCK
   1 OF GRAVITY (LB-IN-SEC-DEGREE UNITS)*///1X,*TIME*,14X,*X DISPLACEM DOCK
   2ENT*,4X,*Y DISPLACEMENT*,4X,*ROTATION*,10X,*X VELOCITY*,6X,*Y VELO DOCK
   3CITY*,8X,*ROTATIONAL VELOCITY*//)                                  DOCK
```

```
      DO 30 I=1,NPTS
      NP=NP+1
      T=T+DT
      IF(NP.LT.NPT) GO TO 651
      NP=0
      X(3,I)=X(3,I)*57.296
      V(3,I)=V(3,I)*57.296
      WRITE (6,847) T,X(1,I),X(2,I),X(3,I),V(1,I),V(2,I),V(3,I)
  847 FORMAT (1X,7(E12.6,6X))
      X(3,I)=X(3,I)/57.296
      V(3,I)=V(3,I)/57.296
  651 CONTINUE
   30 CONTINUE
      WRITE (6,111)
  111 FORMAT (1H1,10X,*ENERGY BALANCE - GROUND COORDINATE SYSTEM (LB-IN-
     1SEC UNITS)*//4X,*TIME*,12X,*X ENERGY*,8X,*Y ENERGY*,5X,*ROTATIONAL
     2 ENERGY*,2X,*TOTAL KINETIC ENERGY*,2X,*NET KINETIC ENERGY LOSS*//)
      T=-DT
      NP=NPT-1
      DO 90 I=1,NPTS
      T=T+DT
      NP=NP+1
      IF(NP.LT.NPT) GO TO 652
      NP=0
      EX=0.5*XM*V(1,I)*V(1,I)
      EY=0.5*XM*V(2,I)*V(2,I)
      ER=0.5*XIC*V(3,I)*V(3,I)
      EKT=EX+EY+ER
      XKELS=XKE-EKT
      WRITE (6,110) T,EX,EY,ER,EKT,XKELS
  110 FORMAT (1X,6(E12.6,5X))
  652 CONTINUE
   90 CONTINUE
      IF(NCON.LE.0) GO TO 48
      WRITE (6,895)
  895 FORMAT (1H1//10X,*OPPOSITE SIDE COLLISION RESPONSE (LB-IN-SEC UNIT
     1S)*//6X,*TIME*,10X,*CRUSH DEFLECTION*,4X,*FRICTION FORCE*,7X,*CRUS
     2H FORCE*,3X,*FRICTION ENERGY*,6X,*CRUSH ENERGY*//)
```

```
      T=-DT
      NP=NPT-1
      DO 896 K=1,NPTS
      T=T+DT
      NP=NP+1
      IF (NP.LT.NPT) GO TO 896
      NP=0
      WRITE (6,220) T,(DD(K,L),L=1,5)
  220 FORMAT (1X,6(E14.6,4X))
  896 CONTINUE
   48 CONTINUE
      IF (ITIE.LE.0) GO TO 283
      WRITE (6,282)
  282 FORMAT (1H1, 7X,*PORT TOW IN SYSTEM FORCES*///14X,*TIME*,5X,*CABLE
     1-1 FORCE*,10X,*ENERGY-1*,5X,*CABLE-3 FORCE*,10X,*ENERGY-3*,5X,*CAB
     2LE-5 FORCE*,10X,*ENERGY-5*//)
      T=-DT
      NP=NPT-1
      DO 284 K=1,NPTS
      T=T+DT
      NP=NP+1
      IF (NP.LT.NPT) GO TO 284
      NP=0
      WRITE (6,103) T,CF(1,K),EP(2,K),CF(3,K),EP(1,K),CF(5,K),EP(3,K)
  284 CONTINUE
      WRITE (6,285)
  285 FORMAT (1H1, 7X,*STBD TOW IN SYSTEM FORCES*///14X,*TIME*,5X,*CABLE
     1-2 FORCE*,10X,*ENERGY-2*,5X,*CABLE-4 FORCE*,10X,*ENERGY-4*,5X,*CAB
     2LE-6 FORCE*,10X,*ENERGY-6*//)
      T=-DT
      NP=NPT-1
      DO 286 K=1,NPTS
      T=T+DT
      NP=NP+1
      IF (NP.LT.NPT) GO TO 286
      NP=0
      WRITE (6,103) T,CF(2,K),ES(2,K),CF(4,K),ES(1,K),CF(6,K),ES(3,K)
  286 CONTINUE
```

```
  283 CONTINUE
      IF(NBUMP.LE.0) GO TO 151
      WRITE(6,152)
      T=-DT
      NP=NPT-1
      DO 153 K=1,NPTS
      T=T+DT
      NP=NP+1
      IF(NP.LT.NPT) GO TO 153
      NP=0
      WRITE(6,220) T,ZBX(K),ZBF(K),ZBFL(K),ZBE(K),ZBEL(K)
  153 CONTINUE
  151 CONTINUE
  152 FORMAT(1H1,7X,*BUMPER RESPONSE (LB-IN-SEC UNITS)*///12X,
     1*TIME*,4X,*CRUSH DISTANCE*,7X,*CRUSH FORCE*,5X,*LATERAL FORCE*,
     26X,*CRUSH ENERGY*,4X,*LATERAL ENERGY*//)
      GO TO 710
  999 CONTINUE
      WRITE (6,1050)
 1050 FORMAT (/////10X,*END OF SUBMITTED DATA HAS BEEN REACHED*)
      STOP
      END
```

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